

CALIFORNIA REGIONAL WATER

JAN 11 1996

QUALITY CONTROL BOARD

MASS EMISSIONS REDUCTION STRATEGY FOR SELENIUM

Staff Report

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OCTOBER 12, 1992

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MASS EMISSIONS REDUCTION STRATEGY FOR SELENIUM: Staff Report

I. INTRODUCTION

Levels of selenium in the San Francisco Bay estuary are a significant cause for concern (SFEP, 1991). Available data on selenium concentrations in Bay organisms indicate that food chains in Suisun Bay, Carquinez Strait, eastern San Pablo Bay, and the South Bay are enriched (a map of the estuary is provided in Fig. 1). Even though ambient selenium concentrations are well below existing water quality objectives, detrimental biological effects may be occurring in the estuary's ecosystem, posing threats to aquatic, avian and human health. Direct uptake of selenium from water does not appear to be the major route of selenium exposure except for primary producers; most aquatic animals obtain the majority of their tissue burden from their diet (Ogle, *et al.* 1988). Selenium's persistence in aquatic ecosystems and its capacity to bioaccumulate¹ through the food chain necessitate a special approach to protect the Bay's beneficial uses.

This staff report presents a consideration of different management alternatives and the scientific justifications for each. After presenting a synthetic review of current information on selenium contamination in the San Francisco Bay Estuary and scientific understanding of selenium in aquatic environments, this document will describe biological assessment guidelines that can be used to assess local food chain enrichment.

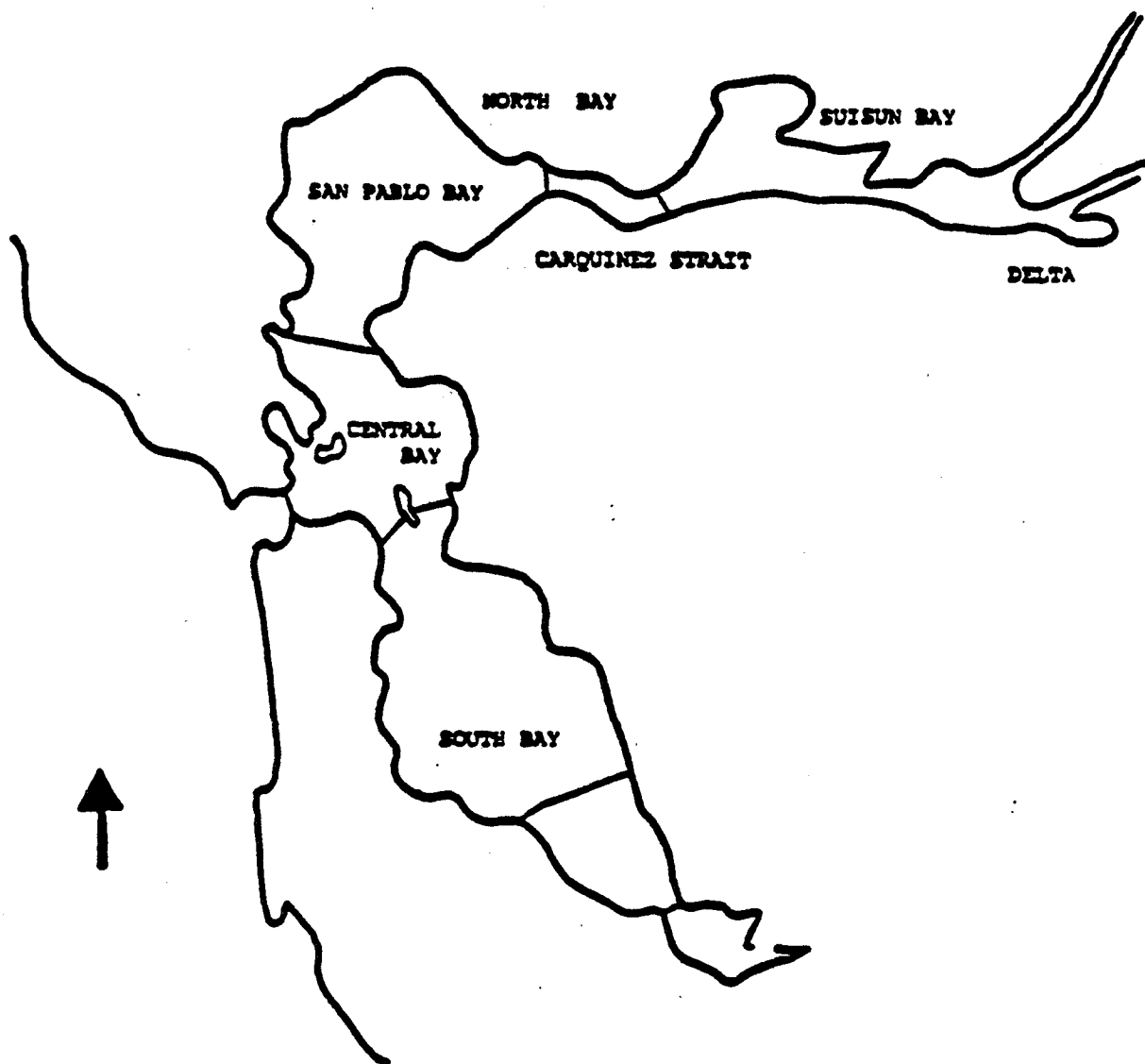
Description of Proposed Activity

While it is possible to estimate water column concentrations of selenium that, in theory, would prevent excess bioaccumulation, such concentrations are poor predictors of food chain enrichment. Like compounds such as DDT, the ecological impact of selenium is most closely associated with mass loading, not concentrations in the ambient water. Therefore, in order to reduce and prevent further impact on the beneficial uses of the San Francisco Bay Estuary, this document presents a proposal for a mass emission reduction strategy.

The goal of the proposed mass emissions strategy is to alleviate the impact of selenium and reduce levels currently found in the food chain. Staff propose a long-

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1. Bioaccumulation involves the total uptake and retention of a chemical by an organism, regardless of exposure pathway. It occurs both through uptake across membranes (bioconcentration) and through ingestion of contaminated food.

Figure 1. Map of the San Francisco Bay Estuary



term goal of reducing anthropogenic selenium loading by 90% over nine years to a level which is comparable to riverine loading during low-flow periods. This target can be achieved by establishing several interim mass emission limits during that period of time, and an iterative process of evaluating food chain enrichment using a series of tissue and water column concentration guidelines. To accomplish this reduction, staff recommend that a limit on total mass loading from all sources be adopted to allow dischargers more flexibility in meeting the reduction schedule.

II. REGULATORY CONTEXT

Inadequacy of existing US EPA and SWRCB water quality criteria for selenium

The San Francisco Bay Region's current water quality objectives for selenium (5 ug/L freshwater and 71 ug/L marine waters) are based on national water quality criteria (SFBRWQCB, 1991; US EPA, 1986). While the SFBRWQCB incorporated these objectives into its most recent Basin Plan amendments, it noted that they may not be fully protective of beneficial uses and undertook to develop site-specific objectives for selenium in the San Francisco Bay estuary. US EPA acknowledges that its existing criteria for selenium have two substantial limitations: 1) national water quality criteria do not completely account for selenium bioaccumulation, and 2) the criteria have not been derived to protect wildlife using selenium-contaminated habitats (Wiltse 1991).

Water quality criteria are usually based on the toxicity of known concentrations of dissolved contaminants to laboratory test organisms. Most laboratory toxicity tests (in both marine and fresh water) show mortality and other adverse effects at or above 50 ug/L selenium (Hamilton *et al.*, 1986; Phillips, 1988). Some data indicate effects at lower concentrations, for example hematological effects in freshwater trout (15-53 ug/L) (Hodson *et al.*, 1980).

To derive total selenium criteria, US EPA first estimated "chronic values" for Se^{+4} and Se^{+6} from toxicity tests using the following equation:

Equation (1)

$$\text{Final Chronic Value} = \frac{\text{Final Acute Value}}{\text{Average (Acute/Chronic Ratio)}}$$

The resulting freshwater values are 28 ug/L (Se^{+4}) and 10 ug/L (Se^{+6}) (US EPA, 1987). However, field research indicates that serious ecosystem-level effects occur when ambient water column levels of total selenium are approximately 10 ug/L (Cumbie and Van Horn, 1979; Lemly, 1985; Gillespie and Baumann, 1986). Aquatic organisms accumulate considerably more selenium through food than they absorb from the water column (Hodson, 1990), and this additional exposure is not accounted for in the

conventional US EPA criteria derivation process. In an effort to incorporate this data about selenium effects after biomagnification through the food chain, US EPA divided its lowest laboratory-based selenium toxicity value by a safety factor of 2 to derive the current freshwater criterion of 5 ug/L.

The laboratory-based marine value is 71 ug/L (Se^{+4}), with insufficient data to calculate a value for Se^{+6} (US EPA, 1987). In contrast to the freshwater criterion, this Final Chronic Value was not adjusted by a safety factor to account for biomagnification, despite substantial evidence in the scientific literature that the pattern of selenium accumulation through marine food chains is very similar to the pattern observed in freshwater systems.

Current guidelines for deriving water quality criteria do not systematically incorporate information on wildlife species (USEPA, 1991a). The general assumption that criteria protective of aquatic organisms (e.g., aquatic plants, invertebrates and fish) will also be protective of other wildlife (e.g., undomesticated mammals, birds, reptiles and amphibians) may not be applicable to contaminants that bioaccumulate through food chains. As noted above, current water quality criteria do not consistently or quantitatively account for selenium's bioaccumulation potential (USEPA, 1991b). US EPA did not estimate a bioaccumulation factor (BAF) for selenium because data were inadequate to derive separate BAFs for its various oxidation states. Furthermore, experimental data indicated an inverse relationship between BAFs and selenium water concentrations. US EPA also lacked an estimate of the maximum acceptable concentration of selenium in tissue because neither a Food and Drug Administration action level (to protect human consumers) nor a National Academy of Sciences predator protection level was available. As discussed in the section "Selenium in Aquatic Ecosystems," the impact of selenium on aquatic organisms and wildlife is primarily due to the total mass of selenium flowing into the food chain, and much less a function of ambient water column concentrations.

Federal Regulatory Requirements

1. Current regulatory requirements based on concern about selenium: Clean Water Act, section 304(l) listing

In September 1990, US EPA identified six petroleum refineries as significant point sources of selenium whose discharges were adversely affecting beneficial uses, particularly sport hunting of waterfowl (Seraydarian, 1990). While their discharges had not led to exceedances of the national water quality criterion for selenium, they contributed to elevated tissue levels of selenium in ducks that are the subject of a state health advisory (CDHS, 1988). On this basis, several northern segments of San Francisco Bay were listed as impacted by selenium from point source discharges under Section 304(l) of the Clean Water Act. In 1991, the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) adopted individual control strategies for the

refineries as required by Section 304(l), specifying interim discharge limits to restrict selenium mass emission rates and a 1994 deadline for all refineries to meet a concentration limit on selenium discharges of 50 ug/L. This limit is based on the US EPA water quality criterion for selenium in freshwater (5 ug/L), with a dilution ratio of 10:1 for deep water discharges.

2. 40 CFR 131.12

Federal Regulations governing antidegradation (40 CFR Section 131.12) and State Board Resolution No. 68-16, "Statement of Policy with Respect to maintaining High Quality Waters in California," require an anti-degradation analysis if higher effluent limitations are expected to lead to an increase in pollutant concentrations or mass loadings above current ambient levels. The proposed mass emissions strategy complies with these regulations because it (a) establishes a mechanism to address toxic 'hot spots;' (b) will maintain or improve existing water quality by reducing mass loading of selenium.

California Regulatory Requirements

1. Porter-Cologne Act

The mass emissions strategy will serve as the basis for effluent limitations. Section 13263 of Porter Cologne requires that in establishing waste discharge requirements, the Regional Board take into consideration beneficial uses to be protected, water quality objectives, other waste discharges, and the provisions of section 13241. The proposed mass emissions strategy was developed to protect beneficial uses and meet the narrative water quality objective concerning bioaccumulation. Section 13241 requires that the following be taken into account: (a) past, present, and probable future beneficial uses of water; (b) environmental characteristics of the hydrographic unit under consideration, including the quality of water available thereto; (c) water quality conditions that could reasonably be achieved through the coordinated control of all factors which affect water quality in the area; (d) economic considerations; (e) the need for developing housing within the region, and (f) the need to develop and use recycled water.

Factors (a) and (b) were considered in discussions presented in this document on selenium levels in the Estuary and impacted beneficial uses, selenium in aquatic ecosystems, and the derivation of ecological assessment guidelines. The proposed mass emissions strategy, which establishes a timeline for loading reductions over a period of several years, accompanied by periodic ecological assessments specifically addresses the 'reasonable achievement' requirement and economic considerations (factors (c) and (d)). This proposal does not affect the need for housing development (factor (e)). The need to develop and use recycled water was explicitly considered during the development of this strategy; one reason staff consider the mass emission

reduction plan preferable to stricter effluent concentration limits is that recycling and/or treatment of waste streams may result in significant decreases in mass emissions, yet slightly higher effluent concentrations.

2. Enclosed Bays and Estuaries Plan (EBEP)

This proposed mass loading reduction strategy implements the narrative criteria presented in the EBEP. The strategy is based on a synthesis of all scientific information currently available on selenium in aquatic systems and specifically addresses the problem of past bioaccumulation. It was developed in keeping with option 2a on page 11 of the EBEP for calculating effluent limitations.

3. California Environmental Quality Control Act (CEQA)

The Regional Board must comply with the requirements of CEQA when amending the Basin Plan. The Basin Planning process has been certified as "functionally equivalent," and this report fulfills the requirements of (1) describing the proposed activity (introduction); (2) discussing and evaluating alternatives to the proposed activity (proposed policy summary and alternatives), and (3) addressing the potential for environmental impacts (Environmental Checklist: Appendix).

III. PROPOSED POLICY SUMMARY AND ALTERNATIVES

There are two basic alternatives for managing the impact of selenium on beneficial uses in the Bay: derive and adopt a site-specific objective that would limit the concentration of selenium in the water column or develop and implement a plan for reducing the mass emissions that does not rely on water column concentration limits. Currently, mass emission caps that exist in discharger permits are derived using water column objectives and dilution limits. A third alternative is to take no action. The no-action alternative would likely result in increased adverse impacts to beneficial uses.

Conceptually, the bioaccumulation-based water quality guideline is based on limiting the total stock of selenium in any segment of the food chain by limiting uptake by plants. While the general approach of limiting the potential for selenium bioaccumulation was generally supported by those commenting on an earlier technical report (Pease *et al.*, 1992), there are several problems associated with the implementation of a water column objective. First, ecological problems associated with selenium appear to be more closely related to mass loading than concentration levels. Second, the major anthropogenic sources of selenium in the estuary, the refineries², may not be able to meet permit limits derived using the current 5 ug/l

². Municipal treatment plants may also be significant sources of selenium. Currently, high analytical detection limits prevent an accurate quantitative assessment of loading

water quality objective. Third, although the proposed criteria would likely be protective, not enough is known about the biogeochemical cycling and biological uptake of selenium to derive predictive relationships.

The advantages to adopting a water quality objective for selenium based on the bioaccumulation-based model (described in more detail later in this report) are that such an objective is a more familiar technical tool in water quality regulation, providing both a means for calculating conventional permit limits on effluent concentration and for indicating whether regulatory actions are indeed affecting ambient concentrations (if modeling of concentrations were possible).

The second approach to managing the impact of selenium in the Bay is to focus on reducing anthropogenic mass emissions. The advantages to this approach are that current knowledge strongly suggests that sediment and suspended material, in addition to water, are also sources for food chain selenium. The only way to limit the biomagnification of selenium, then is to limit the total amount of selenium which ends up in all three compartments. Hence, reducing the total mass loading is a logical method of limiting selenium bioaccumulation. Another advantage is that mass loading reductions may be much more readily achievable than reducing concentration levels in permitted discharges. From an ecological standpoint, it may be more prudent to reduce overall loading into the Bay rather than strictly enforce concentration limits, assuming that issues regarding local hot spots are resolved. A third advantage to the mass emission strategy is that it may allow dischargers more flexibility in meeting regulatory goals.

The disadvantages to using the mass-based approach is that there is little guidance available for developing mass limits in the absence of concentration-based standards. Furthermore, because of the possibility that the Bay sediment has served as a sink for selenium, the long-term effects of mass reductions may not be clearly visible in the short-term.

The no action alternative would not reflect our assessment of the impacts of selenium in the estuary, and would not accomplish the goal of protecting beneficial uses by limiting bioaccumulation of selenium.

Given these two basic approaches, staff recommend a combination of the traditional water quality objective approach and a mass emission reduction strategy. The combined approach would involve establishing several ecological assessment guidelines that would function as an interpretation of the narrative standard and would include concentrations of selenium in total suspended material and organisms in addition to water column concentrations. These assessment guidelines would be

from these sources.

used to periodically evaluate the extent of food chain enrichment in key areas of the estuary. To achieve reductions in food chain enrichment, dischargers would be required to reduce the total anthropogenic mass loading of selenium by a series of percentages over a fixed amount of time. The proposed level of reduction and timetable is presented in Table 7. Reevaluations of ecological impact using the assessment guidelines may establish when load reductions short of the proposed long term goal are sufficient to protect beneficial uses.

The remainder of this document will discuss the technical bases for deriving ecological assessment guidelines (including a water column concentration level) and limits on selenium mass loading into the estuary.

IV. SELENIUM LEVELS IN THE ESTUARY AND IMPACTED BENEFICIAL USES

Food Chain Enrichment

A primary goal of reducing pollutant loading into the San Francisco Bay Estuary is to protect present and future beneficial uses. Levels of selenium found in organisms, suspended material, and the water column (particularly in the South Bay, parts of San Pablo Bay, Carquinez Strait, and Suisun Bay) are significantly above background concentrations; in some cases, these levels are as elevated as those known to cause adverse effects at other field sites.

Two species of diving ducks taken from the Bay exhibit levels of selenium in liver tissue that approach or exceed those associated with reproductive problems among populations of dabbling ducks at Kesterson Reservoir (AHI, 1987). Mean selenium levels in livers³ of birds wintering in San Pablo and Suisun Bays ranged from 14 to 83 ug/g dw for scaup and 40 to 209 ug/g dw for scoters (CDFG, 1988; 1989); mean levels found in liver tissue of adversely affected bird populations at Kesterson ranged from 46 to 82 ug/g dw (SWRCB, 1990c). Although no histopathological effects were observed in these scoters and scaup, a comparison between liver tissue burdens in birds wintering in the Bay and other marine sites (Table 1) shows that selenium burdens in scoters are both considerably higher than background and than other contaminated bays (CDFG, 1988; 1989; Henny *et al.*, 1991). Waterfowl apparently increase their selenium body burdens after arrival in the area and mean body burdens may have increased since 1986 (CDFG, 1988; 1989). Taken together, these data strongly indicate that levels of selenium in the food chain in parts of the Estuary are very high and comparable to levels at which adverse effects on beneficial uses may be expected to occur.

3. Levels in liver tissue are used for comparison because they more closely reflect recent exposure (Heinz *et al.*, 1990).

Selenium levels in eggs from birds nesting in the Estuary also approach levels at which hatchability in nonmarine species may be significantly reduced. Endangered California Clapper rail (*Rallus longirostris obsoletus*) eggs collected throughout the Bay contained levels ranging from 1.3 to 7.3 ug/g dw, compared to 1.2 ug/g dw in rail eggs from an uncontaminated estuary on the east coast (Lonzarich *et al.*, 1991). The highest selenium concentration in the eggs of this endangered species (7.3 ug/g dw) was observed near a refinery in San Pablo Bay. Intensive studies of the effects of selenium on nonmarine birds indicate that normal egg levels range from 1 to 3 ug/g dw; levels exceeding 8 ug/g in populations may significantly affect hatchability and the teratogenesis threshold lies between 13 and 24 ug/g (Skorupa and Ohlendorf, 1991). Although the reproductive success of clapper rails is not thought to be currently affected by elevated selenium levels, elevated levels in eggs suggest that other more sensitive species or birds foraging closer to selenium sources may be adversely affected under current conditions.

Elevated concentrations of selenium in bivalves located in the North and South Bays (2.8 to 5.2 ug/g dw) have been detected since 1975 in filter-feeding clams and

Table 1. Mean Levels of selenium in scoter liver tissue (ug/g dw) collected in late winter from different sites¹

	1982 ²	1985 ³	1987 ⁴	1988 ⁴
San Pablo Bay			138	135
Suisun Bay			69	193
South Bay	34		79 ⁵	
Morro Bay			28	
Humboldt Bay			16	12
Alsea Bay, OR ⁶		23		
Commencement Bay, WA ⁷		21		
Elliott Bay, WA ⁷		43		

Table Notes:

1. Values represent mean [Se] of all samples taken at site between Jan. 1 and April 30 that year. Late winter was considered to be January and later, chosen because better reflects local food sources.
2. Ohlendorf *et al.*, 1986b.
3. All 1985 data from Henny *et al.*, 1991.
4. All 1987-1988 data from CDFG, 1988; 1989.
5. Only one bird was analyzed.
6. Bay on central Oregon coast considered as reference site.
7. Bay in Puget Sound considered to be highly contaminated.

mussels and deposit-feeding clams (Anderlini *et al.*, 1975, Risebrough *et al.*, 1977). The highest selenium tissue concentration yet recorded by the State Mussel Watch Program (3.1 ug/g wet weight (ww)) occurred at the former Union Oil Company outfall in eastern San Pablo Bay. The next highest concentration found statewide in 1988-89 also occurred in San Francisco Bay, at a site near Treasure Island (SWRCB, 1990b). A comparison between bivalves from the Bay and other coastal sites (Table 2) suggests that selenium levels are 1.5 to 2 times background levels (2-3 ug/g dw). While these tissue levels are not expected to cause adverse effects in consuming organisms (see discussion on NOAEL derivation) or bivalves themselves, any degree of biomagnification as selenium passes up the food chain will result in feed concentrations that are a cause for concern (Hodson and Hilton, 1983; Lemly, 1985).

Other organisms in the estuarine ecosystem may also be adversely affected by selenium. Levels found in white sturgeon muscle tissue (~9.2 and 5.9 ug/g dw: SWRCB, 1990a) are very close to the 8 ug/g level of concern reported by Lemly and Smith (1987). Selenium contamination has also been postulated as one of the causative factors in the decline of striped bass populations in the San Francisco Bay estuary (Greenberg and Kopec, 1986; Saiki and Palawski, 1990). Whole body levels in striped

Table 2. Mean levels of selenium in bivalve tissue from coastal and San Francisco Bay sites (ug/g dw)

	January 1987 ¹	October 1987 ²	December 1987 ²	January 1988 ²	February 1988 ²
San Pablo Bay	4.5				
Suisun Bay	4.3	6.4	5.6		5.8
Humboldt Bay	3.1			2.0	

Table Notes:

1. Data for January, 1987 from SWRCB, 1988.

2. Data for other months from CDFG, 1989

Average levels from bivalves at locations generally considered as reference sites sampled during different years were: Trinidad Head: 3.0 ug/g; Bodega Head: 2.5 ug/g (SWRCB, 1988).

bass were found to be as high as 7.9 ug/g dw. This level is below Lemly and Smith's estimate of 12 ug/g dw as a threshold for adverse effects (1987). In addition, the California Department of Health Services (CDHS) has issued health advisories which recommend restricting consumption of diving ducks from San Francisco Bay to protect human health (CDHS, 1986; 1988).

A general summary of selenium levels found in Bay organisms is graphically

depicted in Figure 2; levels considered to be elevated are highlighted⁴. Areas of the Estuary where selenium is a particular cause for concern are Suisun Bay, Carquinez Strait, South San Francisco Bay, and a few sites along the east shore of the Central Bay (Fig. 2; Johns *et al.*, 1988; SWRCB, 1988; CDFG, 1989).

In summary, the available data indicate that selenium levels in the food chain of several segments of the San Francisco Bay estuary are significantly above background levels and are approaching or exceed those known to cause adverse effects in organisms elsewhere.

Selenium in the Water Column and Sediment

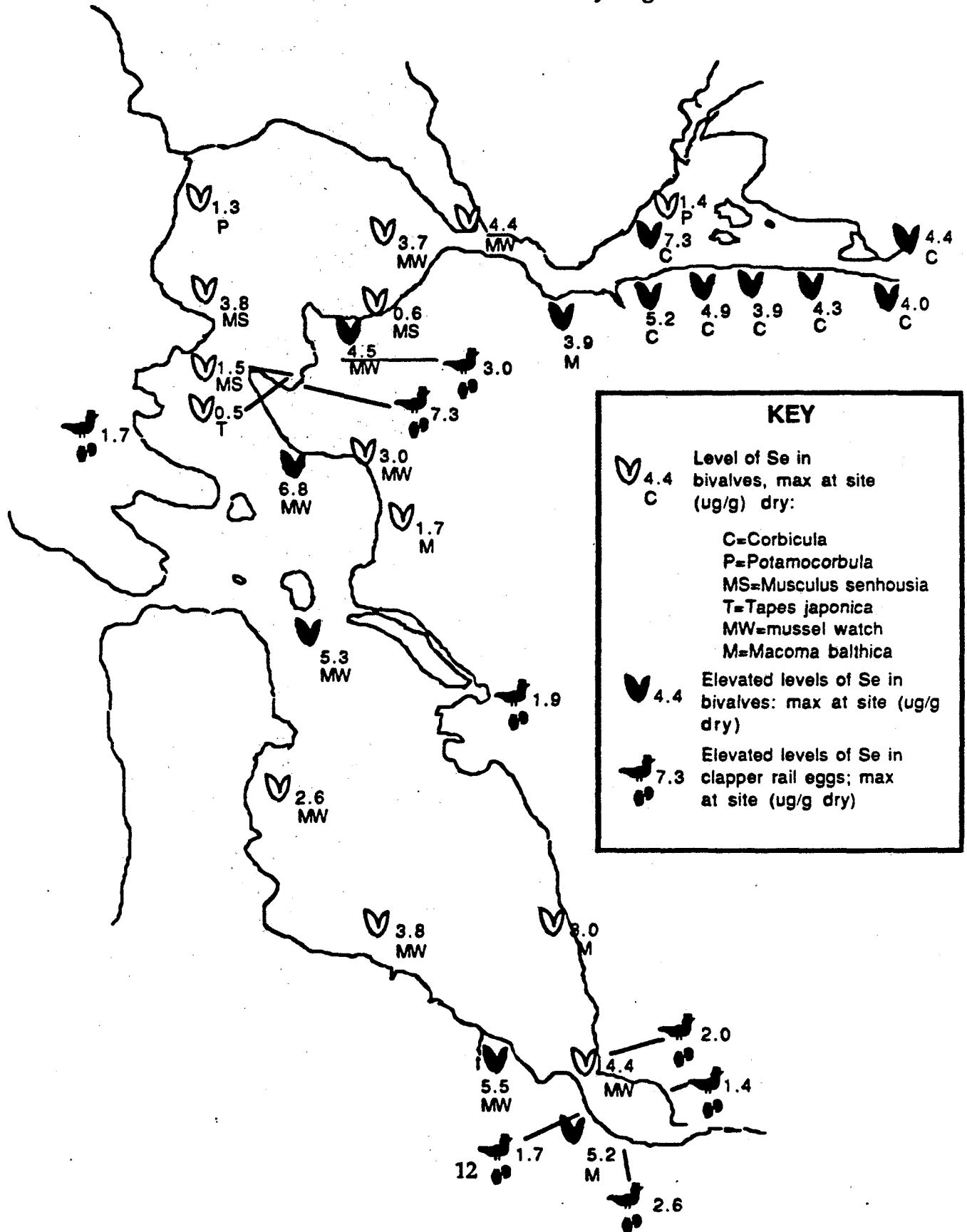
Average total dissolved selenium (Se) concentrations in the San Francisco Bay are approximately 0.1 ug/l (Ball and Arthur, 1986). Higher total selenium concentrations (0.1-0.3 ug/l) have been observed in the South Bay and Carquinez Strait (Cutter, 1989) and near petroleum refinery discharges (0.3-2.7 ug/l) (Friedman, 1992). Selenite concentrations in San Francisco Bay range between 0.015 to 0.1 ug/l (Cutter, 1989). In suspended particulates, total selenium concentrations range between 0.3 - 0.7 ug/g (dw) (Cutter, 1989) and may be composed of inorganic forms bound to particulates (Balistrieri and Chao, 1990) and organic matter (Cutter and Bruland, 1984). In sediment, total selenium concentrations range between 0.2 - 0.5 ug/g dw (Johns *et al.*, 1988) and are composed of elemental selenium (Se⁰), ionic selenium (Se⁺⁴ and Se⁺⁶) and organic forms (Velinsky and Cutter, 1991).

Our current understanding of selenium indicates that adverse ecological effects are primarily caused by selenium in the food chain, rather than selenium dissolved in the water column (Phillips, 1988; Luoma *et al.*, 1992). A recent feeding study conducted using organisms, water and sediment from San Francisco Bay confirmed this effect, demonstrating that the source of 98-99% of the selenium in bivalve tissue was particulate matter (Luoma *et al.*, 1992).

Once in the water column, selenium enters food chains primarily as a result of bioconcentration by phytoplankton. Phytoplankton are consumed in large quantities by crustaceans and bivalves, which are in turn eaten by fish, waterfowl and/or marine mammals. Ingestion of contaminated food results in progressively higher selenium concentrations at higher trophic levels, or biomagnification. Bioconcentration and biomagnification can increase selenium levels more than 1,000 fold from water to fish and animals (Saiki and Lowe, 1987). By far the greatest concentration step occurs

4. Tissue levels in *Corbicula* and *Macoma balthica* were considered elevated if > 3 ug/g dw (see Table 2; Johns *et al.*, 1988); levels reported by the State Mussel Watch were considered elevated if > 4.48 ug/g dw (EDL & SWRCB, 1988); no information on background levels in other species identified in Fig. 2 was found.

Figure 2. Levels of Se Found in Bay Organisms



between water and phytoplankton, with subsequent steps in the food chain typically increasing selenium concentrations by a factor of 2-6 (Lemly and Smith, 1987; Ohlendorf, 1989).

Sources of Selenium Loading

There are several major sources of selenium discharges into San Francisco Bay. The major riverine source of selenium is the Sacramento River except during periods of extremely high flow when there is significant inflow from the San Joaquin drainage basin. While there is generally no significant flow from the San Joaquin into the estuary, selenium loading dramatically increases when water from the San Joaquin reaches the estuary because it typically contains much higher concentrations of selenium. For example, during the period from July, 1984 to April, 1987, there was significant outflow from the San Joaquin into the estuary during only two months: April and May of 1986. Total riverine loading into the estuary during that time was 32 kg/d (April '86) and 5 kg/d (May '86). In comparison, the highest loading from the Sacramento was roughly 3 kg/d (calculations based on data from Cutter, 1989). The ecological impact of selenium from riverine sources is probably mitigated due to the much shorter freshwater residence time during periods of high flow.

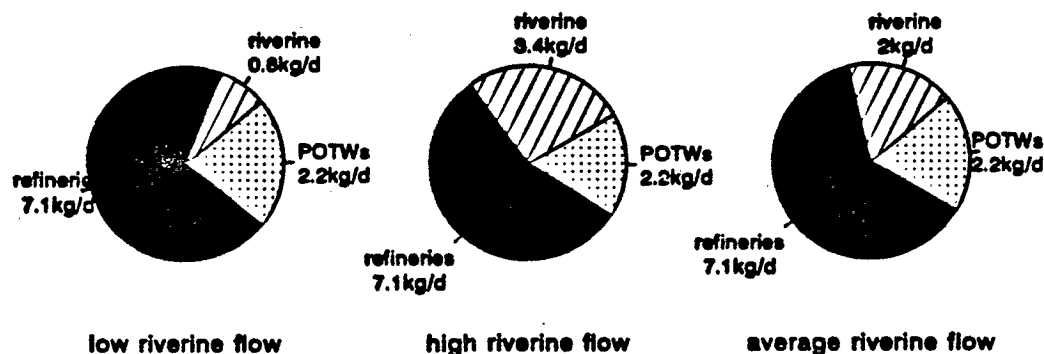
Both the total mass loading from riverine sources and water column concentrations of total selenium flowing into the estuary are greatest during periods of high runoff (Cutter, 1989; Cutter and San Diego-McGlone, 1990). Thus, estimates of riverine loading into the system naturally vary. From July, 1984 to April, 1987, the average riverine input during the three months with the lowest runoff was 0.8 kg/d. Riverine input during the three months with the highest flows (excluding an anomalously high period in April, 1986) averaged 3.4 kg/d total selenium (calculated from Cutter, 1989). There is no significant riverine source of selenium into the South Bay (Cutter, 1989; Cutter and San Diego-McGlone, 1990).

In comparison, refinery and municipal treatment plant (POTW) emissions of selenium generally exceed riverine input, particularly during periods of low flow. Refinery emissions into the Carquinez Strait region were estimated to be an average of 7.1 kg/d during 1991.⁵ Loading from all municipal treatment plants has been estimated at be 2.4 kg/d; however, this estimate is likely to be higher than actual loading from these sources because reported detection limits are high (typically at 1-2

5. Calculated from flow and concentration data in self-monitoring reports, assuming constant loading during the period of time between sample dates.

ug/l).⁶ The maximum input to the South Bay from POTWs, which one report suggests is the primary source of selenium into the South Bay (Gilliom, 1989), is 0.4 kg/d. Figure 3 depicts selenium loading into the Estuary from these sources.

Figure 3. Sources of Selenium Loading into the San Francisco Bay Estuary



V. SELENIUM IN AQUATIC ECOSYSTEMS

Oxidation States

Selenium is present in the water column in dissolved, colloidal and suspended particulate phases. In any of these phases, selenium can occur as different elemental or ionic species. Dissolved in the water column, selenium is generally present in ionic forms such as selenide (Se^{2-}), selenite (Se^{+4}) or selenate (Se^{+6}), although a wide variety of organic forms of selenium occur in varying concentrations (Cutter and Bruland, 1984; Ball and Arthur, 1986; Oremland *et al.*, 1989; Kiffney and Knight, 1990). Particulate forms can be inorganic (especially Se species bound to ferric oxides) or organic. Organic forms of selenium are primarily byproducts of biological processes (Wrench, 1978; Cutter and Bruland, 1984; Reinfelder and Fisher, 1991). Elemental selenium (Se^0) is also found in the aquatic environment; it is considered insoluble and most likely to exist in anoxic sediments or waters (Oremland *et al.*, 1989; Cutter, 1978).

Biogeochemical Cycling of Selenium

The biogeochemical cycling of selenium is highly complex, occurring within and between three different environmental compartments: biota, the water column and sediments. Figure 4 summarizes the important pathways along which different selenium species cycle in the aquatic environment and enter the food chain. Studies of selenium cycling in marine and freshwater systems suggest almost identical patterns

6. Loading from municipal treatment plants was calculated in the same way as loading from refineries: concentration (or detection limit) x flow x period of time between samples. The vast majority of samples from these sources were below detection limit.

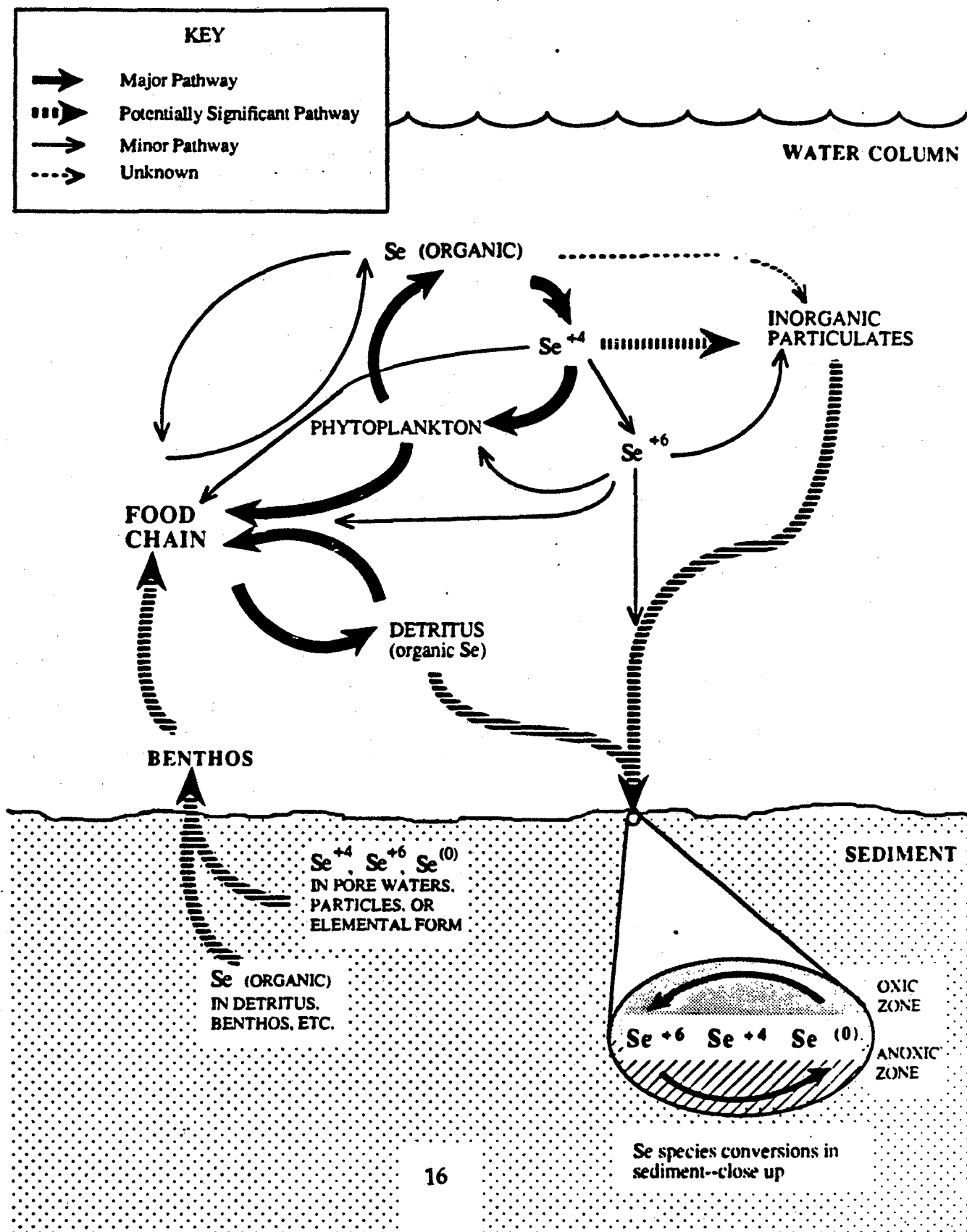
of interaction between the water column and organisms. In freshwater systems and estuaries, sediment interactions also appear to be important (Besser *et al.*, 1989).

In the water column, chemical transformation of selenium species from reduced forms (organic selenium and selenite) to oxidized forms (selenite and selenate) occurs but appears to be a less important factor than biological processes (Measures and Burton, 1978; Burton *et al.*, 1980; Robberecht and Van Grieken, 1982; Cutter and Bruland, 1984). Chemical and physical processes also result in the association of selenium with inorganic particles, most notably iron oxides (Balistreri and Chao, 1990). The predominant dissolved forms of selenium in the water column are selenite and selenate. Naturally occurring organic forms of selenium are also thought to be present in water, but have very short residence times due to rapid oxidation and biological uptake (Robberecht and Van Grieken, 1982).

Aquatic organisms, particularly phytoplankton and other aquatic plants, bioconcentrate dissolved selenium from the water column. The chemical form of selenium will greatly affect the rate of bioaccumulation and ultimate impact of selenium on aquatic organisms (Ogle *et al.*, 1988). Seleno-methionine is accumulated at a greater rate and to a greater extent than selenite or selenate (Hamilton *et al.*, 1990, Heinz *et al.*, 1990). Selenite is accumulated to a greater extent than selenate and is readily reduced and metabolized to form organic selenium compounds. Although selenate can bioaccumulate and elicit toxicity in aquatic organisms, its ability to be reduced, metabolized and incorporated into organisms is apparently lower (Ogle *et al.*, 1988). Organisms generally incorporate selenium into seleno-amino acids, particularly seleno-methionine, and other organic selenide compounds (Stadtman, 1974; NAS-NRC, 1983; Bottino *et al.*, 1984). These organic forms of selenium can then be excreted directly back into the water column or remain bound to the organism. Thus while organic forms of selenium are not prevalent in the water column, aquatic organisms are exposed to seleno-methionine and other forms in plant tissue or detritus (depicted as major pathways in Figure 4).

Biogeochemical cycling of selenium in the sediment may also play a significant role in the overall impact of selenium on aquatic systems. Inorganic forms of selenium can enter the sediment directly from the water column (either through adsorption to particles, bonding to sediment particles, or active biological uptake by microbes) or bound to settling inorganic particulates (depicted as potentially significant pathways in Figure 4). Organic forms of selenium can enter the sediment attached to settling detritus, or excretion by benthic organisms. Once in the sediment, selenium can be reduced to elemental selenium (Oremland *et al.*, 1989; 1990; Steinberg and Oremland, 1990). Generally, reduction of selenium species occurs in anoxic sediments, while oxidation occurs in oxic zones (Velinsky and Cutter, 1991).

Figure 4. Selenium Uptake into the Aquatic Food Chain: Important Pathways



Implications for Preventing Food Chain Enrichment

The current understanding of selenium in aquatic ecosystems strongly suggests that excessive levels in the food chain can only be prevented by limiting the uptake by primary producers such as algae and other aquatic plants. This approach has several advantages:

- 1) Managing the uptake of selenium by phytoplankton will protect beneficial uses throughout the food chain in the San Francisco Bay ecosystem.
- 2) Selenium concentrations in phytoplankton respond quickly to changes in water column levels (Rudd *et al.*, 1980), so the effectiveness of this management strategy may be easy to monitor and result in early, direct benefits to consuming organisms.
- 3) By limiting the maximum potential for selenium bioaccumulation throughout the food chain (following Skorupa and Ohlendorf, 1991), it is less important to quantify such factors as the feeding behavior and digestive physiology of each organism along the food chain.

VI. DERIVATION OF ECOLOGICAL ASSESSMENT GUIDELINES

There is general agreement among scientists working on the environmental effects of selenium that adverse effects on birds and other wildlife are primarily caused by excess levels of selenium in feed (SR Hansen, 1992; Phillips, 1988; Luoma, *et al.*, 1992). The protection of species at higher trophic levels thus requires a regulatory approach which uses the best available data to estimate three values: the highest level of selenium in feed generally considered safe for wildlife, the degree to which selenium concentrations in the food chain are magnified, and the relationship between selenium levels in ambient water to levels in primary producers. Equation (2) describes this conceptual approach in mathematical terms:

Equation (2)

$$\text{Water Column Limit} = \frac{\text{NOAEL (Acceptable level of Se in feed)}}{\text{BMF} \times \text{BCF (algae)}}$$

where

NOAEL = The best estimate of a no-observed-adverse-effect-level of selenium in the feed of higher level organisms;

BMF = Biomagnification factor which represents the degree to which selenium levels

in organisms increase as trophic levels increase;

BCF (algae) = Bioconcentration factor for algae which represents the relationship between levels of selenium in the water column and levels in primary producers.

A water column concentration limit calculated using the equation described above is designed to limit the total amount of selenium potentially available to higher organisms through the food chain by preventing unacceptable levels from accumulating in primary producers such as algae.

Determination of a NOAEL

Most of the scientific literature reviewed for this study reported the lowest concentration of selenium in feed at which adverse effects were observed in test organisms. This value is defined as the lowest concentration at which effects in a treatment group are significantly different than effects in a control group. Technically, this value is the lowest-observed-adverse-effect-level, or LOAEL.

There are two standard methods for estimating an NOAEL from an LOAEL: divide the reported value by a safety factor (usually 2-10), or use the next lowest dose reported by experimenters as the best estimate of an NOAEL (Peterson and Nebeker, 1992). Because there appears to be a very narrow window between levels at which selenium acts as a trace nutrient and levels at which it becomes toxic (Ganter, 1974), the next lowest dose will be used as the best available estimate of an NOAEL in this derivation. A summary of literature studies reporting adverse effects occurring at selenium feed levels less than 10 ug/g dw are presented in Table 2. The information presented in Table 2 indicates that 4 to 6 ug/g of selenium in the form of selenomethionine (Se-meth) is the best available estimate of an NOAEL based on experimental feeding studies.

There is some degree of uncertainty associated with using an NOAEL derived from data on exposure to selenomethionine alone. Inorganic and other organic forms of selenium are also present in organisms upon which wildlife feed. Phillips (1988) estimates that 60-80% of the selenium in freshwater aquatic plants, invertebrates, and vertebrates, and 60-99% in marine plants and animals is organic. It is not known how much of the selenium bound up in organic forms is selenomethionine, other amino acids, or proteins. Although some fraction of the selenium in the food chain may be inorganic or other organic forms (such as proteins) less toxic to fish and wildlife, researchers generally consider selenomethionine to be an excellent tool for modelling environmental exposure (Skorupa and Ohlendorf, 1991).

The conceptual model being used here to derive limits on the total selenium stock in the food chain rests on the assumption that once selenium has entered the food

chain, regardless of whether it is immediately bound up in an organic molecule or

Table 3. Summary of LOAELs and NOAELs of Se in Feed

LOAEL in feed*	NOAEL in feed*	Se form	Effect	Organism	Source
8	4 (est)	Se-meth	hatchability	mallard	Heinz <i>et al.</i> , 1990
	4	Se-meth	[using same data as above]		Peterson and Nebeker, 1992
	< 6.5	Se-meth	parr-smolt transition	chinook	Hamilton <i>et al.</i> , 1986
	5	inorg. and org.	growth	mammals	Peterson and Nebeker, 1992
9.6	5.3 (est.)	Se-meth	survival	chinook	Hamilton <i>et al.</i> , 1990

Table Notes:

* All values in ug/g as Se, dry weight

remains in the inorganic form, it has the potential to be converted into more toxic, organoselenium by subsequent consumers.

Given that available information is limited to toxicity studies of inorganic selenium and selenomethionine, an NOAEL based on the latter was used for two reasons: first, most of the selenium in the food chain is organic and it is reasonable to expect that the toxicity of selenomethionine will more closely approximate that of other organic forms than the toxicity of inorganic selenium; second, a guideline developed using the selenomethionine data will likely be most protective.

Biomagnification of Selenium in the Food Chain

Selenium enters the food chain primarily through direct uptake from the water column by algae and other aquatic plants. Typically, selenium concentrations in phytoplankton are several orders of magnitude greater than ambient water column levels (Table 4). Once in the food chain, however, it appears that concentrations of selenium in tissue do not significantly increase between trophic levels. Reviews of both freshwater (Lemly, 1985) and marine (Phillips, 1988) data indicate that selenium concentrations in the food chain do not increase by more than 2 to 6 times between

Table 4. Levels of Selenium in Water and Algae

Concentration in Water (ug/l)	Concentration in algae/ phytoplankton (ppb dry weight)	BCF	Water type	Lab or field	References
0.051	5.61	110	fresh	lab	Nassos et al., 1980
0.08 *	12000	150000	marine	field	Liu et al., 1987
0.08 *	16900	211250	marine	field	Cutter and Bruland, 1984
0.08 *	27200	340000	marine	field	Fowler and Benayoun, 1976
0.08 *	19500	243750	marine	field	Sandholm et al., 1973
0.08 *	19000	237500	marine	field	Wrench and Measures, 1982
0.15	600	4000	fresh	field	Gutenman et al., 1976
0.2	416	2080	fresh	field	Saiki and Lowe, 1987
0.25	270	1080	fresh	field	Schuler et al., 1990
0.32	1020	3188	fresh	field	Lemly, 1985
0.35	900	2571	fresh	field	Gutenman et al., 1976
0.43	873	2030	fresh	field	Saiki and Lowe, 1987
0.632	213000	337025	marine	lab	Zhang et al., 1990
0.632	68000	107595	marine	lab	Zhang et al., 1990
0.632	11380	18006	marine	lab	Zhang et al., 1990
0.67	1210	1806	fresh	field	Lemly, 1985
0.76	30900	40658	fresh	field	Schuler et al., 1990
0.79	51000	64557	marine	lab	Zhang et al., 1990
0.79	21000	26582	marine	lab	Zhang et al., 1990
0.79	12640	16000	marine	lab	Zhang et al., 1990
8.9	23800	2674	fresh	field	Saiki and Lowe, 1987
10.91	9560	876	fresh	field	Lemly, 1985
40.7	214000	5258	fresh	field	Saiki and Lowe, 1987
68.3	12500	183	fresh	field	Saiki and Lowe, 1987
77	59400	771	fresh	field	Saiki and Lowe, 1987
100	59000	590	fresh	field	Saiki and Lowe, 1987
314	246000	783	fresh	field	Saiki and Lowe, 1987
330	67000	203	fresh	field	Saiki and Lowe, 1987

Table Notes:

* Used estimate of 0.08 ug/l as average concentration of Se in sea water

primary producers and upper trophic levels.

Using the NOAEL of 4-6 ug/g (dry) and a biomagnification factor of 2-6, equation (2) becomes:

$$\text{Water column limit (ug/l)} = \frac{4-6 \text{ ug/g (dry)} \times 1000 \text{ g/kg}}{2-6 \times \text{BCF (algae)}}$$

$$\text{Equation (2)} = \frac{0.67 - 3 \text{ ug/g} \times 1000 \text{ g/kg}}{\text{BCF (algae)}}$$

In summary, it appears that organisms that are the primary food source for fowl and wildlife species (upper trophic levels) generally should not contain more than 4-6 ug/g of total selenium (dw). Similarly, aquatic plants that contain more than 0.67 to 3 ug/g indicate that selenium loading may result in excessive food chain enrichment.

Relationship Between Se Levels in Water and Algae Bioconcentration Factors

1. Algal Bioconcentration Factors

The relationship between levels of a pollutant in water and levels in organisms is typically expressed as a single-value bioconcentration factor. For example, Peterson and Nebeker (1992) use a value of 1200 as a general estimate for the ratio of selenium levels in freshwater species of aquatic plants to selenium levels in the water column. Zhang and others (1990) measured BCFs for three species of marine algae ranging from 16,000 to 337,000, depending on species and water column levels⁷. Using the mean BCF for all three marine species (95,000) to estimate acceptable water column levels in equation (2), the resulting limit would be 0.007 to 0.03 ug/l. Using the BCF for *Skeletonema costatum* (17,000), the resulting limits of total dissolved selenium would be 0.04 to 0.2 ug/l. Selenium levels in the Bay range from 0.07 to 0.36 ug/l (Cutter, 1989).

Using a single value to estimate the potential bioaccumulation of selenium by algae and other plants is problematic for several reasons. First, using such a BCF implicitly assumes that the uptake of selenium from the water column is independent of water column concentrations. Field and experimental data (Figures 5 and 6) clearly demonstrate that this assumption is not warranted.

7. Mean BCF of 95,000 for all three species and 17,000 for *Skeletonema costatum* at 0.63 and 0.79 ug/l.

The data presented in Figures 5 and 6 indicate that the partitioning of selenium between tissue and water varies across water column concentrations. The solid curve represents a possible relationship between plant selenium levels and water column levels where uptake mechanisms are efficient only at low water column levels. The dotted curve (Fig. 5), on the other hand, represents a relationship where there are two independent uptake processes, and each is more efficient at different water column concentrations. Both curves are plausible and demonstrate that plant tissue:water partitioning is complex, non-linear, and can not be definitively explained on the basis of available information. However, the data do suggest that at background levels, selenium levels in phytoplankton are typically several thousand times that of the water column, but as water levels increase, the ratio of selenium in water to tissue decreases.

The second major problem with using a single bioconcentration factor is the difference in uptake by different species of algae. Uptake by *Skeletonema costatum* appears to be passive and likely due to adsorption to the cell wall, whereas uptake by *Chaetoceros muelleri* and *Phaeodactylum tricornutum* appears to be active and due to incorporation of selenium into proteins (Zhang *et al.*, 1990). Algal BCFs reported in the literature range from 18,000-337,000 for marine waters and 110-41,000 for fresh water systems (Table 4), supporting the conclusion that there is a high degree of variability of selenium uptake directly from the water, both across water column concentrations and plant species. Furthermore, even though *Skeletonema costatum* may be the most prevalent form of algae in the Bay, active uptake of selenium by other species may in fact be the dominant pathway by which the element is incorporated into food chains.

The third major problem with using a single bioconcentration factor is that the form of selenium in the water column also affects the rate of uptake by plants. Vandermuelen and Foda (1988) reported that selenite (Se^{+4}) is taken up to a greater extent by algae than selenate (Se^{+6}). Consequently, the speciation of selenium in ambient water is also likely to affect plant uptake and rate of entry into the food chain. Most BCFs measured in laboratory experiments do not take speciation into account.

Although there are significant uncertainties associated with using algal BCFs reported in the literature (and some clear indications of significant conflict between implicit assumptions and knowledge about selenium in environmental systems), there are also advantages. A carefully measured algal BCF is a good indicator of the degree to which selenium enters the food chain through primary producers. Field-based measurements are complicated by the practical impossibility of separating algae from other particulate matter, and the difficulties of identifying different forms of selenium at very low concentrations in any media.

Figure 5. Possible Trends in Se Partitioning Over Range of Water Column Levels: Freshwater
(Data from Saiki and Lowe, 1987; Table 4)

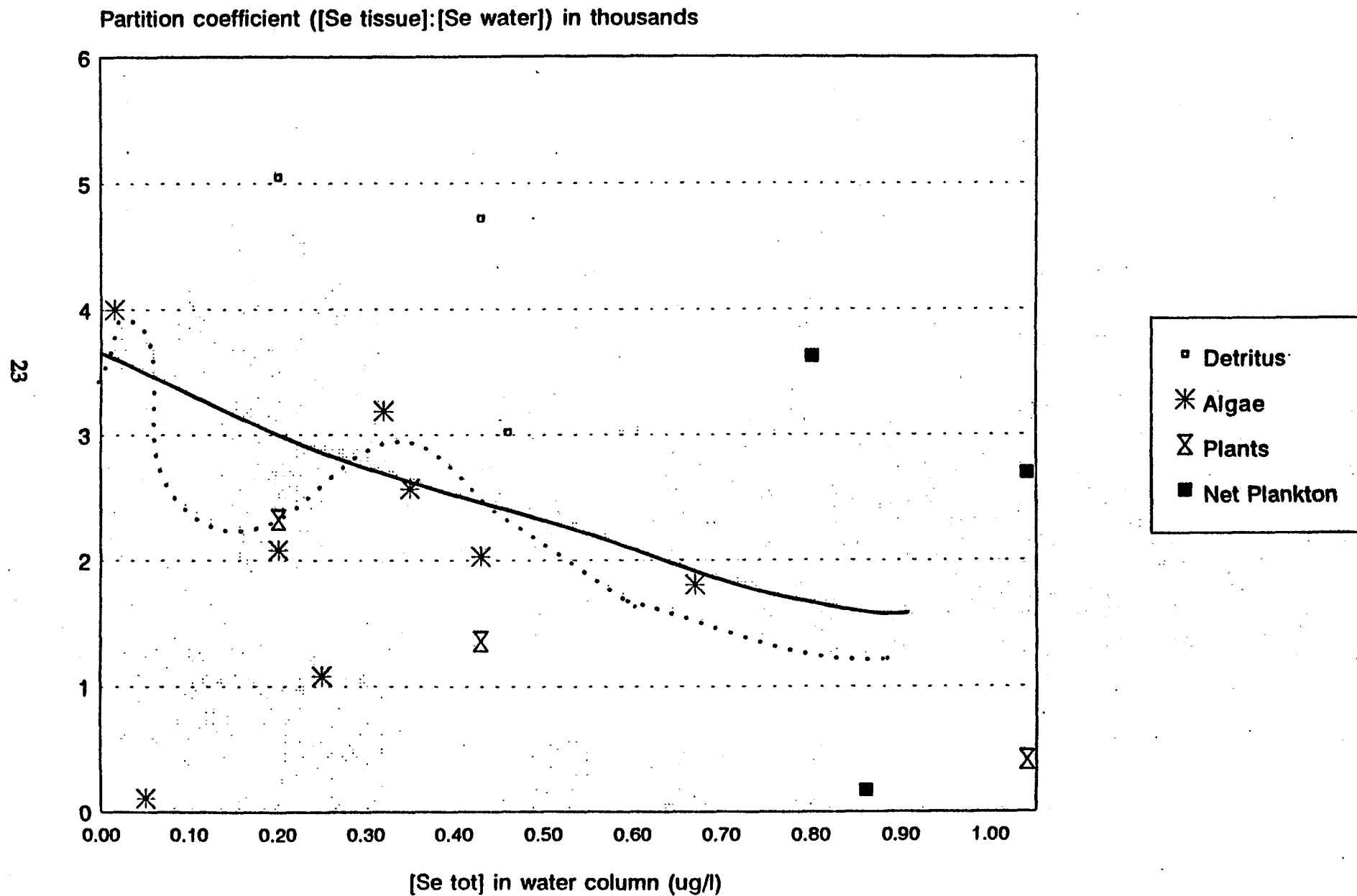
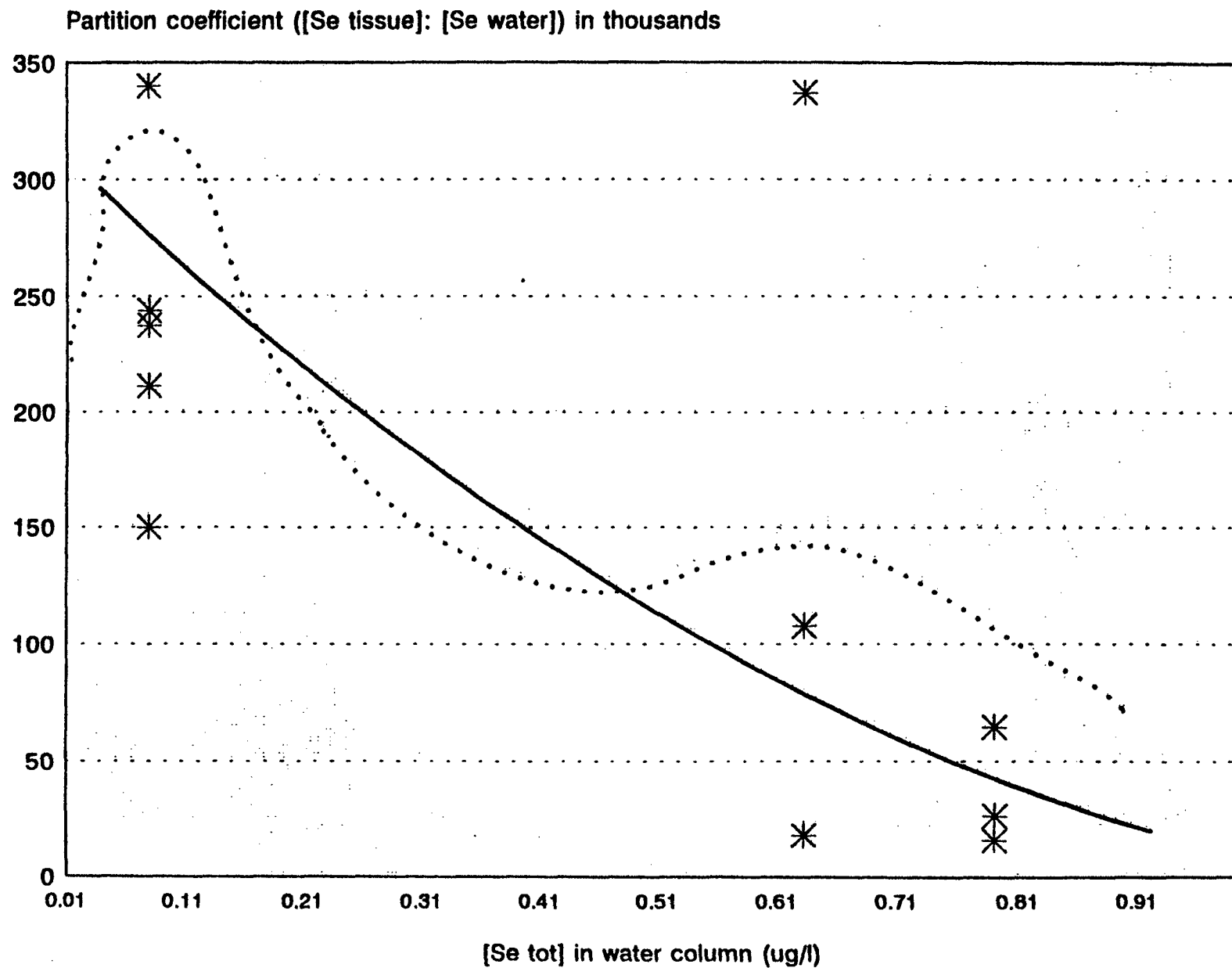


Figure 6. Possible Trends in Se Partitioning Over Range of Water Column Levels: Marine Algae
(Data from Table 4)



2. Selenium in Total Suspended Matter (TSM) and the Water Column

A second method of deriving a relationship between levels of selenium in ambient water and levels in aquatic plants is to use field data reported by Cutter (1989) on selenium forms in the water column and suspended material (TSM) throughout San Francisco Bay. To derive a quantitative relationship between selenium in TSM and dissolved forms, levels of selenium reported in TSM at each sampling station were first transformed into [Se total] in particulate matter (dw). The results were then regressed against dissolved concentrations of selenite, selenate, organic, and total selenium. There was no correlation between dissolved selenate, organic, or total selenium and levels in TSM. There was, however, a relatively strong correlation between dissolved selenite and selenium in TSM (Figure 7), particularly for field-based data ($R^2 = 0.61$, $p < 0.001$).

Data from several sampling stations were not included in the regression presented in Figure 7. The two samples taken at the Golden Gate were excluded for the following reason. The data obtained in September, 1986 at this site strongly suggested a large difference between TSM: selenite partitioning in marine systems and in the Bay (the data point was more than 2 standard deviations away from the TSM level predicted by the unadjusted regression line). It is reasonable to expect suspended material in marine systems to contain more and/or different species of phytoplankton than suspended material in the Bay, which is likely to contain more inorganic matter. Although the data obtained in April of the same year in a nearby location are similar to data from the rest of the Bay, both samples taken at the Gate were excluded from the regression analysis. It is not known whether the September samples were taken at high tide. The other data point excluded from the regression was the sample taken at station 26 in September, 1986; the point was more than two standard deviations away from the unadjusted regression line and analytical problems were reported by the author (Cutter, 1989).

Based on the regression in Figure 7, the relationship between selenite in the water and selenium in TSM can be expressed as:

Equation (3)

$$[\text{Total Se}] \text{ in TSM (ug/g dw)} = 0.2 + 7.8 [\text{Se}^{+4}] \text{ in water (ug/l)}$$

using the range of acceptable selenium levels in algae from equation 2 as limits on selenium in TSM: $0.67 < [\text{Total Se}] \text{ in TSM (ug/g dw)} < 3.0$, equation 3 can be solved for the maximum level of $[\text{Se}^{+4}]$ in water (ug/l):

$$0.06 \leq \max [\text{Se}^{+4}] \text{ (ug/l)} \leq 0.36$$

Although this analysis of site-specific data does not provide a precise estimate of

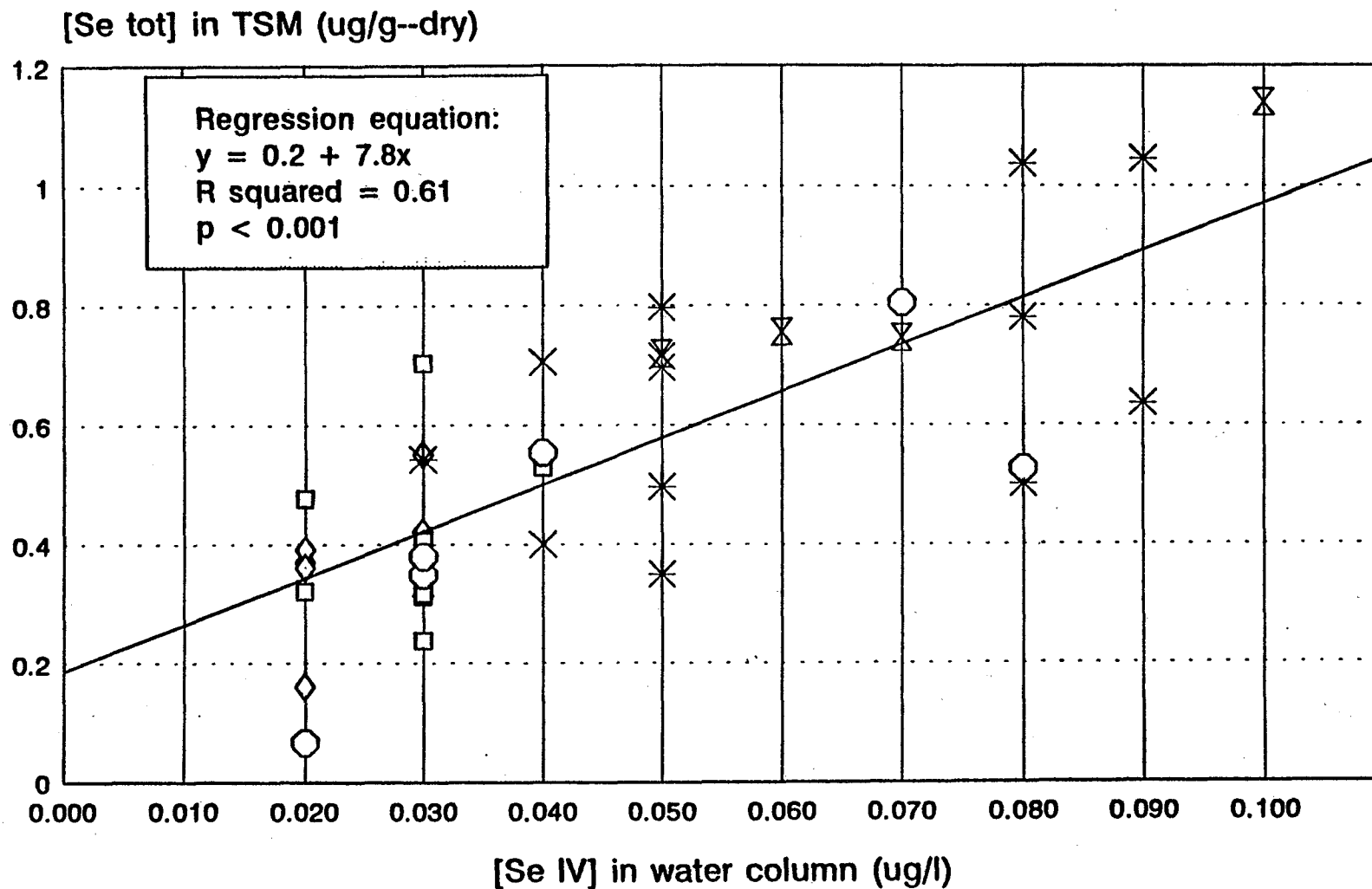
average bioconcentration of selenium by phytoplankton in the Bay, examining the partitioning⁸ of selenium between the water column and TSM is useful. Because the analyzed suspended material is a mix of inorganic and organic particulates, it is likely that the relationship described by equation (3) falls between [Total Se on inorganic particulates]:[Se⁺⁴] and [Total Se in phytoplankton]:[Se⁺⁴]. As such, equation (3) represents the best estimate of phytoplankton:[Se⁺⁴] partitioning that can be derived on the basis of available field data. Using the range of 0.67 - 3 ug/g (dw) as the maximum acceptable level in algae (from equation (2)), the acceptable water column concentration for selenite ranges between 0.06 and 0.36 ug/l. Data from two of the sampling stations in the South Bay, all of the stations in Carquinez Strait, and two stations in the Suisun Bay/Delta area exceeded 0.06 ug/l selenite; all stations were below 0.36 ug/l.

As in the case of using a single-value bioconcentration factor, there are uncertainties associated with the TSM partitioning model. TSM is not a precise means of estimating phytoplankton: selenite partitioning, mainly because it is analytically impossible to separate inorganic from organic particulates. Furthermore, the basic conceptual approach of limiting selenium entry into the food chain by limiting uptake by primary producers does not take other pathways such as ingestion of selenium on inorganic particles into account. Although significant amounts of selenium may enter the food chain through inorganic particulates (Luoma *et al.*, 1992), little is known about how this pathway compares to active uptake by plants.

The water quality concentrations for selenite derived using the TSM partitioning model does not address other forms of dissolved selenium. Recent studies suggest that selenate (Se⁺⁶) and elemental selenium may also contribute to selenium levels in the food chain, but not necessarily through algal uptake. While selenate exhibits less direct toxicity to aquatic organisms than selenite and is not as easily bioaccumulated, this form of selenium remains a substance of concern because in most parts of the estuary selenate levels are higher than selenite levels (Cutter, 1989). Selenate is the dominant form (85-90%) of selenium present in irrigation waters in the San Joaquin Valley (Bruland and Cooke, 1986) where substantial adverse impacts on avian populations have been detected. Luoma and others (1992) have recently demonstrated that elevated levels of selenium in benthic organisms from San Francisco Bay result from exposure to sediment. One of the most important forms of selenium in sediment is elemental selenium, which is precipitated by microbial dissimilatory reduction of selenate. Selenium fixed in this manner is transferred to animals less efficiently than

8. The partitioning of selenium between different environmental compartments is a more accurate term here than BCF. Technically, a BCF only describes the biological uptake of a pollutant. In this case, it is analytically impossible to separate selenium which has been bioconcentrated from selenium which is bound to inorganic particulates in the TSM.

Figure 7. [Se] in TSM vs [Se IV] in water column
San Francisco Bay, April and Sept., 1986



○ South Bay	□ Central Bay	× North Bay
* Carquinez Strait	⊗ Suisun Bay/ Delta	◇ Sacramento River

organo-selenium in food, but a significant fraction (20% of the sediment-sorbed selenium) is biologically available (Luoma *et al.*, 1992).

Although the cycling of selenium through the estuary's benthic environment may prove to be as important as algal uptake of selenite, not enough is known at this time to calculate specific guidelines for other forms of selenium based on this pathway. The importance of cycling, however, strongly indicates that limiting the total amount of selenium entering the Bay is necessary to protect against food chain enrichment.

In the absence of detailed bioaccumulation data on the other forms of selenium, a guideline for total selenium in the water column can be derived using the difference between algal uptake of selenite and selenate. We have assumed that selenate is the second most ecologically significant chemical form, and that the total impact of all selenium species (except selenite) can be estimated from selenate data. This approach may underestimate the amount of selenate that is bioavailable because it does not explicitly consider the selenate/sediment pathway, for which quantitative data are unavailable. Vandermeulen and Foda (1988) report uptake of Se^{+4} and Se^{+6} for several algal species and water column concentrations. Using their values for 0.079, 0.79, and 7.9 $\mu\text{g/l}$, the average ratio of Se^{+4} to Se^{+6} uptake by four species of algae was calculated as 20 (range at lower concentrations: 21-30). This ratio defines the relative contributions of selenite and selenate to the total amount of selenium that is bioconcentrated by phytoplankton. The maximum acceptable concentration of selenium in TSM (T_{max}) is therefore a function of the bioconcentration of different selenium species, or:

Equation (4)

$$T_{\text{max}} = [\text{Bioconcentration of } \text{Se}^{+4}] + [\text{Bioconcentration of } \text{Se}^{+6}]$$

Using our previously estimated bioconcentration relationship for Se^{+4} (equation 3) and the assumption that Se^{+6} bioconcentration is 1/20th of Se^{+4} bioconcentration, equation (4) becomes:

Equation (5)

$$T_{\text{max}} = (0.2 + 7.8 [\text{Se}^{+4}]) + (1/20)(0.2 + 7.8[\text{Se}^{+6}])$$

or

$$T_{\text{max}} = 0.2 + 7.8 [\text{Se}^{+4}] + 0.4 [\text{Se}^{+6}]$$

This equation indicates that for any given value of T_{max} , allowable concentrations of dissolved selenite and selenate are dependent on the relative percentages of the different species in the water column. The solution to equation (5) is presented in

Figure 8 for $0.67 < T_{\max} < 3 \text{ ug/g Se (dry)}$. The lower line represents the most stringent ecological assessment guidelines for total selenium (where TSM levels are not allowed to exceed 0.67 ug/g dw). As the relative percentage of selenite increases, the maximum allowable concentration of dissolved selenium decreases from 1.1 ug/l to 0.06 ug/l . The upper line represents water column levels that will theoretically prevent levels of selenium in TSM from exceeding 3 ug/g (dw) ; the maximum allowable concentration of total dissolved selenium under this scenario ranges from 7 to 0.4 ug/l .

Comparison of water column assessment guidelines developed from BCF and TSM partitioning models to field data

There is a considerable amount of field data on selenium levels in the water column, sediment, and organisms in the Bay which can be used to evaluate the models developed above.

Data from Cutter's (1989) water column analyses were used to estimate the general areas of the Bay that would exceed four different criteria: 0.2 ug/l total selenium in water derived using the literature-based algal BCF information⁹ (Figure 9), 0.67 ug/g in TSM¹⁰ (Figure 10), $0.06 \text{ ug/l Se}^{+4}$ (equation 3; Figure 11), and the limits on total selenium derived using 0.67 ug/g as the maximum acceptable level in TSM and relative proportions of Se^{+4} and Se^{+6} (lower range from equation 5; Figure 12). As graphically depicted in Figures 8-11, all four guidelines are exceeded in Suisun Bay and Carquinez Strait—both areas where elevated levels of selenium in organisms are consistently found.

The models that appear to best predict food chain enrichment are the proportional limit (equation 5) and TSM guideline. The latter suggests that elevated levels of selenium will be found in the area from mid-Suisun Bay, east into sections of San Pablo Bay, near Angel Island, and sections of the South Bay. The proportional guideline suggests food chain enrichment throughout the South Bay, but not as extensively in San Pablo Bay. In contrast, the guideline based on the literature algal BCF does not predict any enrichment in the South Bay. Therefore, we recommend that the proportional limit and TSM guideline be used as ecological assessment guidelines in evaluating compliance with the narrative toxicity objective.

9. The criteria based on algal BCFs ranged from $0.04 - 0.2 \text{ ug/l}$ total selenium. The upper end of the range was chosen because the lower value was below all concentrations observed in the Bay.

10. The lower end of the range was chosen because concentrations of selenium in TSM were less than 3 ug/g in all samples.

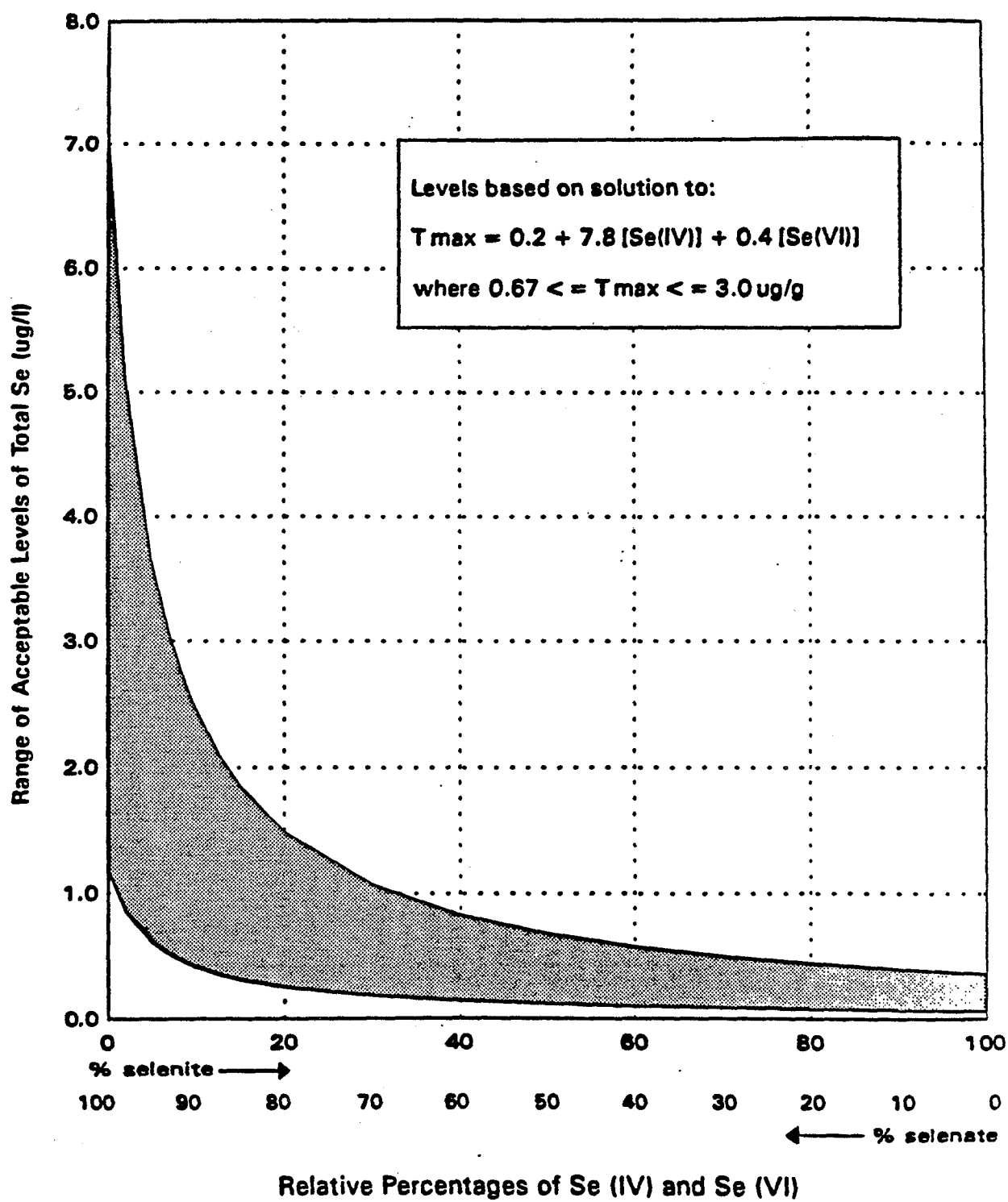
Sediment

There is less information available on the levels of selenium in Bay sediment and very little on the relationship between food chain enrichment and the partitioning of selenium into and out of sediment and the benthos. One recent study, however, strongly indicates that sediment levels higher than 1.5 ug/g (dw) are a cause for concern (Luoma *et al.*, 1992).

Bivalves

As discussed in the section on food chain enrichment in the Estuary, levels of selenium in Bay bivalves are elevated in comparison to levels found at coastal reference sites. Tissue levels higher than 4 ug/g dw are cause for concern because they would exceed the best estimate of an NOAEL for wildlife feed. A protective ecological assessment guideline must take the possibility of biomagnification after bivalves are consumed, yet not be set at a level below a reasonable estimate of background concentrations. Consequently, the best available information suggests that the assessment guideline be set at 3 ug/g dw in bivalve tissue.

Figure 8. Range of Acceptable Levels of Total Se (ug/l) vs.
Relative Levels of Se (IV) and Se (VI)



KEY

- General area where [Se tot] > 0.2 ug/l
- Elevated levels of Se in bivalves: max at site (ug/g dry)
- Elevated levels of Se in clapper rail eggs: max at site (ug/g dry)

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KEY

- General area where [Se tot] in TSM > 0.67 ug/g dry
- Elevated levels of Se in bivalves: max at site (ug/g dry)
- Elevated levels of Se in clapper rail eggs; max at site (ug/g dry)

Map showing sampling locations and selenium (Se) concentrations in bivalves and clapper rail eggs in the San Francisco Bay Area. The map includes the San Francisco Peninsula, the Golden Gate, and the San Francisco Bay. Shaded areas indicate where total selenium (Se tot) in TSM is greater than 0.67 ug/g dry. Sampling locations are marked with bivalve symbols (for bivalves) and clapper rail symbols (for eggs), with numerical values indicating the maximum selenium concentration at each site.

Location (Approximate)	Se Concentration (ug/g dry)	Sample Type
San Francisco Bay (North)	7.3	Bivalves
San Francisco Bay (East)	4.4	Bivalves
San Francisco Bay (South)	4.0	Bivalves
San Francisco Bay (West)	4.3	Bivalves
San Francisco Bay (North)	3.9	Bivalves
San Francisco Bay (East)	3.9	Bivalves
San Francisco Bay (South)	5.2	Bivalves
San Francisco Bay (West)	4.9	Bivalves
San Francisco Bay (North)	4.5	Bivalves
San Francisco Bay (East)	3.0	Bivalves
San Francisco Bay (South)	1.7	Bivalves
San Francisco Bay (North)	7.3	Bivalves
San Francisco Bay (East)	6.8	Bivalves
San Francisco Bay (South)	5.3	Bivalves
San Francisco Bay (North)	1.9	Eggs
San Francisco Bay (South)	2.0	Eggs
San Francisco Bay (East)	1.4	Eggs
San Francisco Bay (North)	5.5	Bivalves
San Francisco Bay (South)	1.7	Bivalves
San Francisco Bay (East)	5.2	Bivalves
San Francisco Bay (South)	2.6	Eggs

Figure 11. Geographic Relationship Between Elevated Levels of Se in Water and Organisms: [Se IV] > 0.06 ug/l

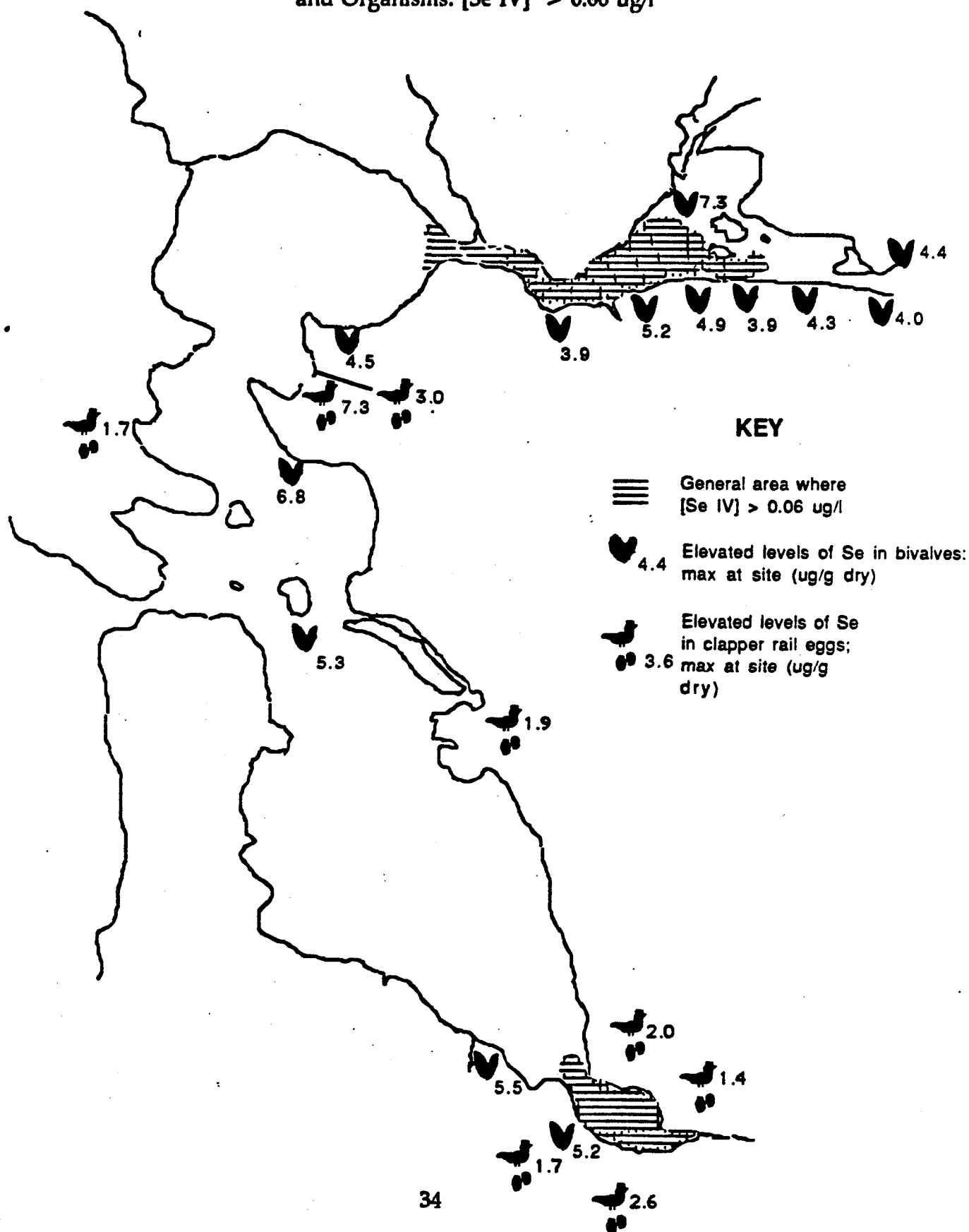
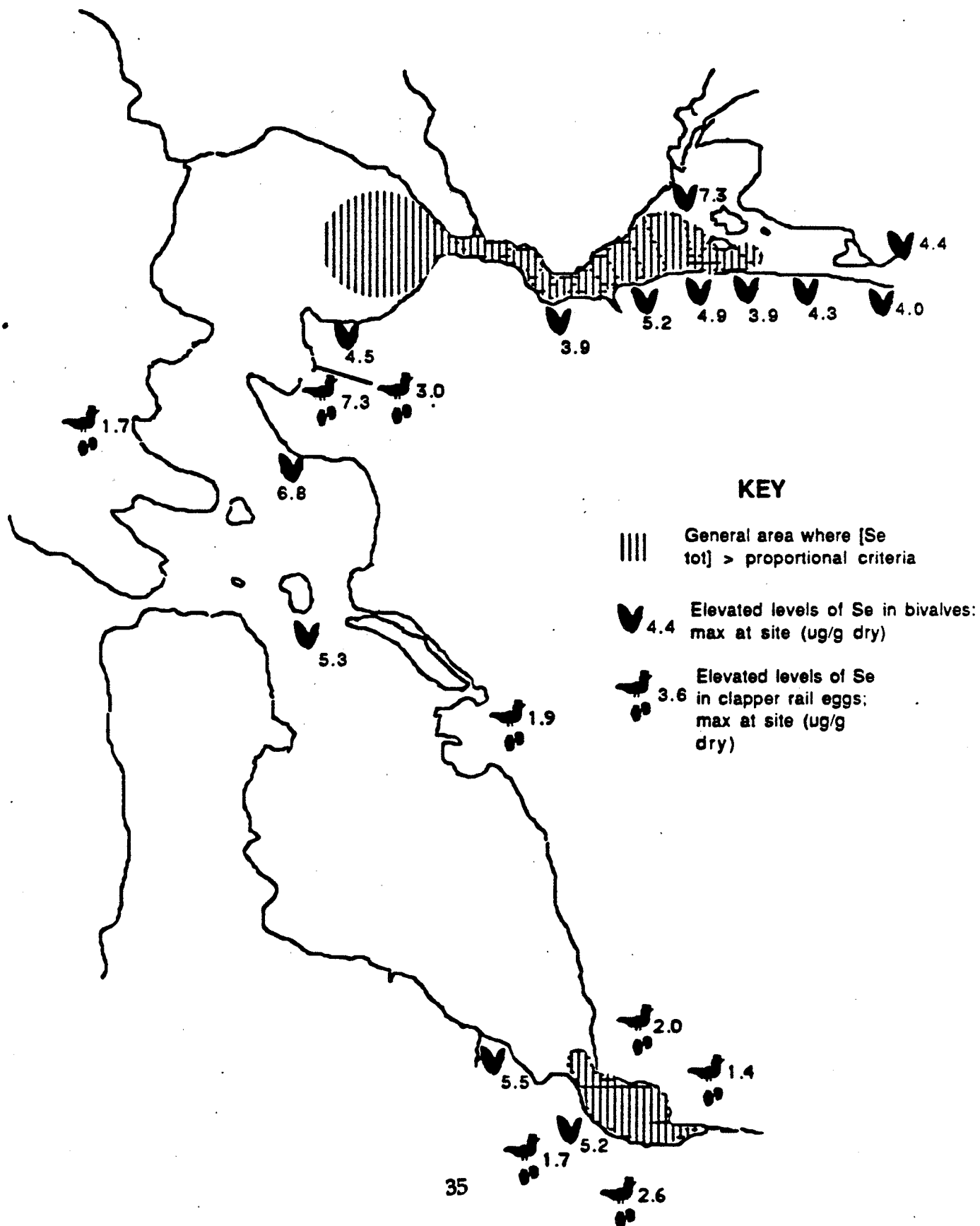


Figure 12. Geographic Relationship Between Elevated Levels of Se in Water and Organisms: [Se tot] in water > proportional guideline



Summary of Guidelines for Ecological Assessment

The current state of knowledge on selenium in the aquatic environment, its ecological impacts, and data on current levels in the San Francisco Bay ecosystem suggest that a series of tissue and water column concentrations can be used to assess food chain enrichment.

These guidelines are presented in Table 5.

Table 5. Summary of Ecological Assessment Guidelines

Organism Type/ Compartment	Guideline
Water	Proportional guideline: max [total dissolved Se] ug/l in water (all forms) = Σ [Se ⁺⁴] + [Se ⁺⁶], where limits on [Se ⁺⁴] ug/l and [Se ⁺⁶] ug/l are defined by equation 5: $0.47 = 7.8$ [Se ⁺⁴] ug/l + [Se ⁺⁶] ug/l (see discussion below)
Total Suspended Material (> 0.45 um)	0.7 ug/g dw
Algae and other aquatic plants	0.7 ug/g dw
Sediment	1.5 ug/g dw
Bivalves	3 ug/g dw

The water column assessment guidelines can be applied in the following manner. A water sample is analyzed for [Se+4], [Se+6], and total dissolved selenium. If, for example, the [Se+4] is 0.4 [Se+6], the maximum acceptable level of total dissolved selenium is calculated by substituting 0.4 [Se+6] into equation 5, yielding a limit of 0.15 ug/l. This method of calculating the limit reflects the difference in bioaccumulation potential between Se+4 and Se+6 and the fact that significant levels of organic forms of selenium are generally not present in natural waters and that organic forms have been shown to be much more bioavailable than inorganic forms.

VII. MASS LOADING REDUCTION STRATEGY

To protect beneficial uses in the San Francisco Bay estuary from the adverse impacts of selenium bioaccumulation, selenium discharges should be substantially reduced. Because the information required to estimate the precise percentage reduction required is unavailable, Staff recommend an iterative approach to reducing selenium inputs to the Bay. Implementing a mass reduction strategy will require two approaches: one for the refineries which have been shown to be the predominant source of selenium during conditions of low flow (the worst-case environmental scenario: EPA, 1991b) and a second implementation plan for the municipal treatment plants and associated problems in the South Bay. In both cases, allowable discharges of selenium should be reduced incrementally, until selenium concentrations in ambient water, sediment, algae and indicator organisms no longer exceed the concentration guidelines developed in the preceding section.

Reducing Refinery Emissions

Refinery discharges of selenium are the predominant source of selenium loading into the Estuary, representing between 56 - 70% of total selenium input to the Bay system. The Board's current approach to protecting the aquatic ecosystem from excess selenium levels emphasizes compliance with effluent limits derived from the existing selenium water quality standard and is reflected in the refineries' NPDES permits. The refineries are currently required to comply with a selenium effluent limit of 50 ug/l as well as interim and final mass emissions rates.¹¹ If refineries comply with the permit conditions by December 1993, refinery selenium discharges to the Bay will be reduced 46% from 1990 loading. More stringent effluent limits, derived from the water column guidelines described in this report, could eventually be used to obtain even further reductions if necessary.

While the current approach to reducing selenium discharges through effluent limits is most familiar to regulators and the regulated community, it has several important weaknesses that undercut its usefulness as a means to limit mass emissions. Compliance with the 50 ug/l effluent limit is proving technically and economically difficult for three refineries (Shell, Union, Exxon) and the refineries together have exceeded the interim limits on mass loading specified in their permits. It currently appears unlikely that the existing permits will in fact produce a 46% decrease in selenium discharges to the Bay.

11. Final permit limits on mass emissions for Shell, Unocal, and Exxon are based on compliance with the 50 ug/l effluent limit and their 1990 average flow. Final permit mass emissions for Tosco, Pacific, and Chevron are based on their maximum annual average daily mass loading during the period 1988-90. Interim permit limits are based on their maximum annual average daily mass loading during the period 1988-90.

Focusing on compliance with a uniform effluent limit can conflict with our principle management goal - reducing the mass loading of selenium into the Bay. The NPDES permits allocate responsibility for selenium emissions reductions on the basis of effluent concentrations, not on the basis of cost-effective control or actual contribution to total loading. Exxon and Chevron, for example, currently discharge similar amounts of selenium (approximately 1 kg/d); but only Exxon is required to reduce its loadings further because it does not comply with the effluent limit. Ignoring the wide range of control options and costs that different refineries face in controlling selenium (WSPA, 1992), the current management approach emphasizes obtaining selenium reductions from the firms with the highest costs and greatest dependence on selenium-enriched crude supplies. This strategy effectively seeks reductions where they are going to be hardest to get, creating noncompliance problems and delay in obtaining environmental quality goals.

The proposed mass emissions strategy involves defining a total limit on selenium loading from all refineries and reducing that limit over the course of time. This strategy is similar to tradeable permit systems used by EPA to achieve the phase-out of lead in gasoline and will allow the dischargers much more flexibility in meeting the emission reduction requirements. After fixing the total amount of lead to be allowed in gasoline during its phase-out as a fuel additive, EPA allowed refiners to bank and trade lead usage rights to create incentives for those with the least costs to reduce quickly and to allow those with higher costs more flexibility in changing their processes to eliminate lead (US EPA, 1985a&b).

1. Establishing a baseline selenium load

Reductions in Se loadings will be calculated from a baseline emissions estimate. Table 6 displays the annual selenium load from refineries into San Francisco Bay for the period 1989 - 1991.¹² The average refinery selenium loading over these years (2162 kg/yr) will serve as the baseline for the mass emission reduction strategy.

12. Loading figures calculated by using weekly selenium analysis results, assuming the effluent flow over the time period between analyses was equal to the flow on the sample date.

Table 6. Annual Refinery Selenium Loads (kg/yr) into San Francisco Bay

	1989	1990	1991	1992 ¹	Average Load ²
Shell	451	745	962	1259	719
Unocal	687	823	860	810	790
Chevron	247	297	257	121	267
Exxon	198	272	369	352	280
Tosco	116	73	111	97	100
Pacific	7	6	7	8	6
TOTAL	1706	2216	2566	2647	2162

Table Notes:

1. 1992 loading estimated by doubling loading from 1/1/92 to 6/30/92.

2. Average load for 1989-1991.

2. Timetable for Emission Reductions

The three stages of the mass emissions reduction program are

a) achieve the reduction currently required by NPDES permits (total load of 1212 kg/yr);

b) subsequently reduce the mass loading from refineries below the selenium loading from riverine sources during high flow (764 kg/yr);

c) further reduce mass loading to 75% of the baseline load¹³ (540 kg/yr) at which point a review of local effects monitoring data to determine the degree to which the ecological assessment guidelines are being met and whether further emission reductions are necessary; and

d) if necessary, further reduce annual selenium loading from refinery sources to 90% of the baseline load—a level which is comparable to input from riverine sources during low flow periods.

The timeline for achieving this series of goals is presented in Table 7.

13. This target has been identified as an interim goal for the purposes of designing control systems in discussions between WSPA and Board staff.

Table 7. Proposed Emission Reductions and Schedule

Year (Jan- Dec)	Total Amount of Permitted Se Loading (kg/yr)	Cumulative Reduction From Baseline ^a
1995	1212 ^b	44%
1996	988	54%
1997	764 ^c	67%
1998	541 ^d	75%
1999	541 ^e	75%
2000	324	85%
2001	216 ^f	90%

Notes:

a Baseline was defined as the average annual loading during '89-'91 (2162 kg/yr) and was calculated using selenium concentration data, flow on sampling date, and number of days between samples.

b Emission levels required by current NPDES permits.

c Refinery loading equal to average riverine loading

d Preliminary goal discussed as target for control technologies.

e Review of ecological monitoring data to determine if further emissions reductions are necessary.

f Refinery loading comparable to riverine loading during periods of low flow.

Unacceptable ecological impacts occurring in the immediate vicinity of these discharges, as determined by the ecological guidelines, may be mitigated by requiring additional controls and/or containment of selenium at that site.

Municipal Treatment Plants

All of the POTW effluent discharged into the Estuary currently meets the 5 ug/l water quality objective. Despite this, excessive levels of selenium in the food chain have been found in the extreme South Bay. At the present time, relatively high analytical detection limits used in effluent analyses (typically 1 ug/l) do not allow for a precise determination of POTW contribution to selenium loading. The quantities presented in Figure 3 were derived assuming effluent concentrations equal to reported detection limits. The first step in addressing loading from POTWs is to obtain an accurate assessment of selenium loading from these sources by conducting a short-term, intensive monitoring scheme with target analytical detection limits at 0.01 ug/l. This step will be completed by June 30, 1993. The second step is to follow the same procedure described above for the refineries: establish an upper limit on mass emissions and reduction schedule if necessary.

Stormwater Sources

Past researchers have concluded that POTWs are the major contributors of selenium loading into the South Bay (Gilliom, 1989). However, stormwater runoff or groundwater extracted from areas with seleniferous soils may also contribute significant amounts of selenium to the Bay system. Selenium concentrations in these waters have generally not been assessed; when analyzed, they have been below analytical detection limits. The first step in addressing loading from stormwater runoff and treated groundwater is to obtain a more precise estimate of mass loading from these sources by requiring participants in the stormwater program and entities discharging treated groundwater to submit monitoring data (target detection limit 0.01 ug/l) by June 30, 1993. The second step is to establish an upper limit of loading from these sources and, if necessary, a reduction schedule.

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**RESPONSES TO COMMENTS RECEIVED ON "TECHNICAL REPORT: DERIVATION
OF SITE-SPECIFIC WATER QUALITY CRITERIA FOR SELENIUM
IN SAN FRANCISCO BAY" BY SFBRWQCB**

Several changes were made in approach proposed in the technical document released in February (Pease *et al.*, 1992) in response to comments received at the SFBRWQCB. This section describes staff responses both to the general themes in the comments and specific responses to key technical issues. To facilitate the discussion, a list of the organizations/ individuals who submitted comments follows:

Organization	Author	Client (if applicable)	Date Received
US EPA Region IX	C. Kuhlman		6/5/92
Larry Walker Associates (LWA)	C. Suverkropp	City of San Jose	6/1/92
Region 5: Central Valley Board (CVRWQCBB)	D. Westcot		5/14/92
CVRWQCB	L. Wass		4/23/92
US Geological Survey (USGS)	S. Luoma		4/7/92
Western States Petroleum Association (WSPA)*			6/30/92
S.R. Hansen and Associates		WSPA	6/30/92
The Bay Institute	E. Gardner		4/30/92
US Fish and Wildlife Service (USFWS)	G. Heinz		4/27/92
Santa Clara Valley Audubon Society (SCVAS)	T. Mulvey		5/28/92
Citizens for a Better Environment (CBE)	G. Karras		5/26/92
SWRCB	J. Diaz		5/1/92
Management Technology (ManTech)	J. Peterson	US EPA	5/1/92

* extension granted on return of comments

1. General Method: Focus on food chain routes of exposure and algal-based criteria derivation

There was a general concurrence that this approach is an appropriate way of preventing adverse impacts on beneficial uses (SWRCB; SR Hansen; US EPA; CBE;).

2. Biomagnification and exposure at different trophic levels

In the original technical report, the proposed limit on total Se in algae was derived solely on the basis of toxicity studies of Se in wildlife feed. This approach did not account for any magnification of selenium levels in the food chain after algal uptake (US EPA; USGS; ManTech; CBE; SCVAS). To address this, a biomagnification factor has been included in the current proposal.

3. Ecological assessment

US EPA suggested that mid-trophic alert levels be developed by making use of available tissue concentration data and that sediment criteria using benthic exposure models should also be considered (as did the Bay Institute).

Ecological assessment guidelines (or "alert levels") have been proposed for organisms (algae and bivalves) as well as sediment, total suspended material, and the water column in response to this suggestion. In addition, information on selenium levels in bivalves, bird eggs, fish, and wildfowl in the estuary were used to evaluate different criteria derivation models.

4. Derivation of acceptable levels in algae

Many respondents commented on the derivation of acceptable levels of selenium in algae based on toxicological exposure studies. Several pointed out that the lower value of 1.5 ug/g was used inappropriately (LWA; USGS; WSPA; SR Hansen), and in general that the choice of an NOAEL had to be clarified (US EPA). Peterson (ManTech) also suggested that a risk-based exposure assessment also be conducted.

In response to these comments, the discussion of how a NOAEL range was chosen was made much more explicit. A risk-based exposure assessment was not conducted because staff do not feel there is adequate information available to quantify the necessary parameters (see discussion on conceptual approach of limiting flow of Se into food chain vs. predicting Se levels).

5. Derived values for limits on Se in TSM and water higher than those observed in the Bay and calculated by extrapolating beyond the range of the data

Most respondents pointed out the conceptual problems associated with this issue (CVRWQCB; SWRCB; USGS; LWA; ManTech; WSPA; SR Hansen; CBE; LWA; SCVAS). The changes made in the proposed model have eliminated this problem.

6. Relationship between Se in TSM and Se in algae

Several commentators pointed out that it is not known how the bioavailability of inorganic forms of selenium in suspended particulates differs from the bioavailability of suspended organic selenium, and that the ratio of inorganic to organic selenium in TSM is not known (LWA; CVRWQCB; CBE). SR Hansen discussed the lack of any relationship between levels of selenium in TSM and chlorophyll levels in the data used in this analysis and stated that "there is not enough information available with which to estimate bioaccumulation accurately" (SR Hansen, p. 15) (also CVRWQCB).

As discussed in the text of this and the original proposals, using the partitioning of selenium between the water column and TSM is not an exact model. The uncertainties inherent in estimating the bioaccumulation of selenium either with the TSM data or more traditional bioconcentration studies (see "Selenium in suspended particulates and the water column"), and rationales behind choices made in the derivation of the ecological assessment guideline are discussed extensively in the text.

7. Relative amounts of inorganic and organic selenium in algae

SR Hansen made the point that not all of the selenium taken up by the dominant form of algae in the Bay (*Skeletonema costatum*) may be transformed into organoselenium. As discussed in the "Determination of a NOAEL" section of the text, there are four reasons why use of selenomethionine data is reasonable: 1) A high percentage of selenium in the food chain is organic, 2) organisms which consume inorganic selenium in algae (including bacteria) can potentially transform the selenium into an organic form, 3) toxicity of alternate forms of organoselenium more likely to resemble toxicity of selenomethionine than inorganic selenium, and 4) selenomethionine is generally considered an excellent tool for modelling the relationship between avian reproductive problems and environmental exposure.

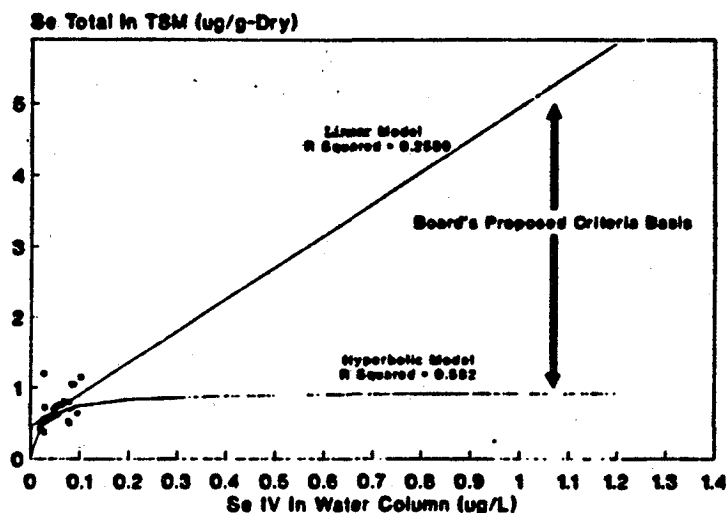
Comments from the CVRWQCB also pointed out that preliminary research results suggest that the organic forms of selenium found in the food chain are independent of the chemical speciation of selenium in the ambient water.

8. Regression analysis and quantification of uncertainty

Several comments suggested that the rationale for not including several data points in the regression be made explicit, that the April data should be used in addition to the September data, and that p-values should be reported (US EPA; LWA; SR Hansen;

CVRWQCB). This discussion was added to the text.

WSPA stated that the linear regression model used may not be appropriate and that a hyperbolic model provided a better fit with the data. Their proposed hyperbolic model suggests that selenite would not accumulate in TSM above 1 ug/g (dry) at water column concentrations above 0.5 ug/l and is reproduced here.



Data patterns from other sources clearly indicate a) that selenium levels in the food chain do increase as water column concentrations increase and b) that the overall partitioning of selenium is a highly complex process. Given the state of knowledge on algal uptake across different water column levels, staff chose to use the simplest regression model rather than a more complex curve providing a "better" statistical fit.

Several commentors also suggested that an effort be made to quantify uncertainties associated with the proposed model (CVRWQCB; LWA; ManTech). Rather than attempt to quantify the uncertainties, the qualitative discussions of uncertainties surrounding each choice in the development of the proposed strategy were clarified.

9. Measurement of total selenium for enforcement purposes

The SWRCB asked for a clarification of how the measurement of "total selenium" would be determined, given that selenide can be a significant percentage of the total amount in the water column. The description of the ecological assessment guideline for levels of selenium in the water column has been clarified.

10. Sediment

Several commentors suggested a more detailed treatment of sediment-related questions (ie. determining the relationship between Se in sediment and Se in TSM)

(SWRCB; US EPA; CBE). As discussed in the report, the sediment is likely to prove an important pathway for selenium biogeochemical cycling in the Bay. However, not even basic information on levels in sediment (only three analyses were found: Johns *et al.*, 1988) was found for this analysis.

11. Evidence of elevated levels of selenium in estuarine organisms

SR Hansen questioned the degree to which tissue levels of selenium found in Bay waterfowl were actually elevated, citing several studies in which individual birds from reference sites were found to have higher levels of selenium in their tissue than birds from San Francisco Bay. In response, the discussion of selenium in Bay organisms in comparison with levels found at other sites has been expanded.

12. Implementation

The suggestions relating to implementation of the proposed strategy highlighted two key issues: a need to develop mass loading limits (SCVAS) and to devise a plan to use new ecological monitoring data (Bay Institute) as it becomes available in the future to inform Board action. The USGS suggested a plan of using biomonitoring coupled with mass loading reductions because it is (and will be) impossible to accurately predict the ecosystem response. US EPA commented on the need to consider more ecological information as the data became available, and the SWRCB suggested developing a mass loading limit "developed in light of the effects-based evaluation contained in the report" (SWRCB, p. 2). CBE recommended that biomonitoring and a requirement for mass loading reductions based on narrative standards be implemented "until this monitoring demonstrates that elevated selenium concentrations no longer threaten sensitive Bay organisms" (CBE, p.5).

All three suggestions were incorporated into the current proposed strategy.

APPENDIX: ENVIRONMENTAL CHECKLIST

I. Background

1. Name of Proponent:
San Francisco Bay Regional Water Quality Control Board
2. Address and Phone Number of Proponent:
2101 Webster Street, Suite 500
Oakland, CA 94612
(510)464-0702
3. Date Checklist Submitted:
October 23, 1992
4. Agency Requiring Checklist:
Resources Agency
5. Name of Proposal, If Applicable:
Amendments to the Water Quality Control Plan,
San Francisco Bay Basin: Mass Emission Reduction Strategy for Selenium

II. Environmental Impacts:

(Explanations of all "yes" and "maybe" answers are provided on attached sheets.)

	<u>Yes</u>	<u>Maybe</u>	<u>No</u>
1. Earth. Will the proposal result in:			
a. Unstable earth conditions or changes in geologic structures?			x
b. Disruptions, displacements, compaction or overcovering of the soil?			x
c. Change in topography or ground surface relief features?			x
d. The destruction, covering or modification of any unique geologic or physical features?			x
e. Any increase in wind or water erosion of soils, either on or off the site?			x

	<u>Yes</u>	<u>Maybe</u>	<u>No</u>
f. Changes in deposition or erosion of beach sands, or changes in siltation, deposition or erosion which may modify the channel of a river or stream or the bed of the ocean or any bay, inlet or lake?			x
g. Exposure of people or property to geologic hazards such as earthquakes, landslides, mudslides, ground failure, or similar hazards?			x
2. Air. Will the proposal result in:			
a. Substantial air emissions or deterioration of ambient air quality?			x
b. The creation of objectionable odors?			x
c. Alteration of air movement, moisture or temperature, or any change in climate, either locally or regionally?			x
3. Water. Will the proposal result in:			
a. Changes in currents, or the course of direction of water movements, in either marine or fresh waters?			x
b. Changes in absorption rates, drainage patterns, or the rate and amount of surface runoff?			x
c. Alterations to the course or flow of flood waters?			x
d. Change in the amount of surface water in any water body?			x
e. Discharge into surface waters, or in any alteration of surface water quality, including but not limited to temperature, dissolved oxygen or turbidity?		x	
f. Alteration of the direction or rate of flow of ground waters?			x

	<u>Yes</u>	<u>Maybe</u>	<u>No</u>
g. Change in the quantity of ground waters, either through direct additions or withdrawals, or through interception of an aquifer by cuts or excavations?			x
h. Substantial reduction in the amount of water otherwise available for public water supplies?			x
i. Exposure of people or property to water related hazards such as flooding or tidal waves?			x
4. Plant Life. Will the proposal result in:			
a. Change in the diversity of species, or number of any species of plants (including trees, shrubs, grass, crops, and aquatic plants)?			x
b. Reduction of the numbers of any unique rare or endangered species of plants?			x
c. Introduction of new species of plants into an area, or in a barrier to the normal replenishment of existing species?			x
d. Reduction in acreage of any agricultural crop?			x
5. Animal Life. Will the proposal result in:			
a. Change in the diversity of species, or numbers of any species of animals (birds, land animals including reptiles, fish and shellfish, benthic organisms or insects)?		x	
b. Reduction of the numbers of any unique, rare or endangered species of animals?			x
c. Introduction of new species of animals into an area, or result in a barrier to the migration or movement of animals?			x
d. Deterioration to existing fish or wildlife habitat?			x

	<u>Yes</u>	<u>Maybe</u>	<u>No</u>
6. Noise. Will the proposal result in:			
a. Increase in existing noise levels?			x
b. Exposure of people to severe noise levels?			x
7. Light and Glare. Will the proposal produce new light or glare?			x
8. Land Use. Will the proposal result in a substantial alteration of the present or planned land use of an area?			x
9. Natural Resources. Will the proposal result in:			
a. Increase in the rate of use of any natural resources?			x
b. Substantial depletion of any nonrenewable natural resource?			x
10. Risk of upset. Will the proposal involve:			
a. A risk of an explosion or the release of hazardous substances (including, but not limited to, oil, pesticides, chemicals or radiation) in the event of an accident or upset conditions?			x
b. Possible interference with an emergency response plan or an emergency evacuation plan?			x
11. Population. Will the proposal alter the location, distribution, density, or growth rate of the human population of an area?			x
12. Housing. Will the proposal affect existing housing, or create a demand for additional housing?			x
13. Transportation/Circulation. Will the proposal result in:			
a. Generation of substantial additional vehicular movement?			x
b. Effects on existing parking facilities, or demand for new parking?			x

	<u>Yes</u>	<u>Maybe</u>	<u>No</u>
c. Substantial impact upon existing transportation systems?			x
d. Alterations to present patterns of circulation or movement of people and/or goods?			x
e. Alterations to waterborne, rail or air traffic?			x
f. Increase in traffic hazards to motor vehicles, bicyclists or pedestrians?			x
14. Public Services. Will the proposal have an effect upon, or result in a need for new or altered governmental services in any of the following areas:			
a. Fire protection?			x
b. Police protection?			x
c. Schools?			x
d. Parks or other recreational facilities?			x
e. Maintenance of public facilities, including roads?			x
f. Other governmental services?			x
15. Energy. Will the proposal result in:			
a. Use of substantial amounts of fuel or energy?			x
b. Substantial increase in demand upon existing sources of energy, or require the development of new sources of energy.		x	
16. Utilities. Will the proposal result in a need for new systems, or substantial alterations to the following utilities:			
a. Power or natural gas?			x
b. Communications systems?			x
c. Water?		x	
d. Sewer or septic tanks?		x	

v

	<u>Yes</u>	<u>Maybe</u>	<u>No</u>
e. Storm water drainage?		x	
f. Solid waste and disposal?		x	
17. Human Health. Will the proposal result in:			
a. Creation of any health hazard or potential health hazard (excluding mental health)?			x
b. Exposure of people to potential health hazards?			x
18. Aesthetics. Will the proposal result in the obstruction of any scenic vista or view open to the public, or will the proposal result in the creation of an aesthetically offensive site open to public view?			x
19. Recreation. Will the proposal result in an impact upon the quality or quantity of existing recreational opportunities?			x
20. Cultural Resources.			
a. Will the proposal result in the alteration of or the destruction of a prehistoric or historic archaeological site?			x
b. Will the proposal result in adverse physical or aesthetic effects to a prehistoric building, structure, or object?			x
c. Does the proposal have the potential to cause physical change which would affect unique ethnic cultural values?			x
d. Will the proposal restrict existing religious or sacred uses within the potential impact area?			x

Yes

Maybe

No

21. Mandatory Findings of Significance.

- a. Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause fish or wildlife population to drop below self-sustaining levels, threaten to eliminate a plant or animal community, reduce the number or restrict the range of a rare or endangered plant or animal or eliminate important examples of the major periods of California history or prehistory? x
- b. Does the project have the potential to achieve short-term, to the disadvantage of long-term, environmental goals? (A short-term impact on the environment is one which occurs in a relatively brief, definitive period of time while long term impacts will endure well into the future). x
- c. Does the project have impacts which are individually limited, but cumulatively considerable? (A project may impact on two or more separate resources where the impact on each resource is relatively small, but where the effect of the total of those impacts on the environment is significant). x
- d. Does the project have environmental effects which will cause substantial adverse effects on human beings, either directly or indirectly? x

IV. Determination:

X On the basis of this initial evaluation: I find that the proposed project COULD NOT have a significant effect on the environment, and a NEGATIVE DECLARATION will be prepared.

— I find that although the proposed project could have a significant effect on the environment, there will not be a significant effect in this case because the mitigation measures described on an attached sheet have been added to the project. A NEGATIVE DECLARATION WILL BE PREPARED.

— I find the proposed project MAY have a significant effect on the environment, and an ENVIRONMENTAL IMPACT REPORT is required.

10.13.92
DATE

Martin Brannan
SIGNATURE

For:
San Francisco Bay Regional
Water Quality Control Board

ENVIRONMENTAL CHECKLIST: explanations.

- 3.e** The proposal may result in improvements to surface water quality, due to reductions in selenium loading to the Bay. Based on technical studies supporting this proposal, it is likely that reducing mass loading will increase rather than result in any decrease in the protection of beneficial uses in the Bay.
- 4.a** Reduced selenium levels in the Bay could result in greater numbers or greater diversity of aquatic plants. Based on current knowledge summarized in the technical report, it is too speculative to determine the degree to which diversity may be affected.
- 5.a** Reduced selenium levels in the Bay could result in greater numbers or greater diversity of aquatic organisms. Based on current knowledge summarized in the technical report, it is too speculative to determine the degree to which diversity may be affected.
- 15.b** Reducing the mass loading of selenium into San Francisco Bay may require the use of different sources of crude oil than currently being used by refineries and thus the development of new sources of oil. There are, however, many options for changing the mix of refined crude and treatment options which would not require such measures.
- 16.c** If POTWs are significant sources of selenium due to storage of water in reservoirs with seleniferous soils, some alteration of water supply methods may be required to reduce mass loading into San Francisco Bay. It is too speculative at this point to determine whether there would be any adverse impacts as a result of possible changes.
- 16.d** The proposed mass emissions strategy for selenium may require reductions in mass loading from sewage treatment plants. It is unlikely that such alterations would result in adverse impact as there will likely be many options for reducing selenium loading that have no adverse impacts such as source control measures.
- 16.e** Information obtained in the future through this action may indicate significant sources of selenium in stormwater runoff. If this is the case, control measures may require some alterations to drainage and/or treatment. It is too speculative to assess the potential impact of possible alterations at this point.
- 16.f** Treatment technologies eventually developed and installed to reduce mass loading of selenium may increase solid waste. However, as the technologies have not yet been determined, it is too speculative at this point to assess the potential impact of waste generation.